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A DYNAMIC MODEL OF THE INDIRECT FIRE SUPPORT BATTLE

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SUMMARY

In this study the dynamic aspects of the indirect fire support battle are discussed with respect to the allocation and control of weapons systems. A detailed computer simulation is then developed using DYNAMO, a special purpose simulation language developed for use in dynamic modeling. The resulting model has some 650 equations. This simulation is tested for sensitivity on three hypothetical weapons mixes, two of which are closely similar to the present mix, and one of which is varied to an extreme within cost and personnel constraints.

The development of the complex model of two-sided battle consumed most of the author's effort and time ran out before a thorough analysis of the sensitivity and consistency of the model could be completed. Although the degree of sensitivity could not be established it appears that the model is sensitive to changes in mix parameters and further analysis and development is recommended.

CHAPTER I

INTRODUCTION

The United States Army Infantry Board, whose responsibility it is to represent infantry units in the research and development process, is conducting a study of infantry indirect fire weapons. A recent review of test methodologies (1) reveals that carefully controlled field tests of equipment are envisioned with human and organizational variables eliminated. There can be little doubt that controlled testing and evaluation of new (and old) weapons is necessary, but it also appears significant to consider these weapons in the light of human and organizational variables. The effectiveness of these weapons depends not only on physical properties but also depends on how and by whom the weapon is to be used. For example, a fire support weapon which fires a 40 millimeter round only 400 meters might be eliminated out of hand in competition with other fire support weapons. But this weapon, the M79 Grenade Launcher is used at squad level, very close to the enemy where its small size and light weight provide high explosive fire which is greatly appreciated by front line infantrymen. Clearly the level in the Army organization at which this weapon is controlled is a key factor in its effectiveness, regardless of how effectiveness is defined.

Analysis which includes organizational variables is difficult in the field. Testing of weapons mixes within a brigade for example would require many repetitions of each proposed configuration and involve, at a minimum, all of the indirect fire control elements of the brigade. Under the current organization this would be nearly 400 men. Even this effort would produce only questionable results because of the difficulty in accounting for learning rates of crews as new configurations and weapons are introduced. Most importantly, however, combat conditions can only be approximated for the obvious safety reasons.

This kind of evaluation question is best approached through modeling techniques of operations research, but because of the complexity of organizational problems, we can expect only to assist subjective decision makers in comparing alternatives.

Historically, organization and operating doctrine have been the framework for providing new answers to weapons mix questions. The military concept with which we are dealing here is that certain men and equipment belong to a certain unit, such as a company and the unit commander is free to use these men and equipment as he thinks best to accomplish his assigned missions. These men and their equipment are termed organic to the unit. While the unit is relatively independent in its conceptual use of organic assets, units do not in fact often operate independently (e.g., companies are nearly always organic to battalions just as platoons are organic to companies). The formal statement of one unit's responsibilities to another is called operating doctrine. Some responsibilities are quite obvious and need little explanation (e.g., battalions are responsible to supply food and ammunition to assigned and attached companies). But other operating doctrines are not obvious, indeed they may be purely arbitrary. This is because the purpose of doctrine is not necessarily to accomplish a task efficiently. It is rather to insure that all actions and responsibilities are understood by all parties, and unnecessary confusion is avoided.

Because of these difficulties we must talk of the allocation of control of weapons systems rather than simply the allocation of weapons themselves. The allocation of the weapons themselves may or may not be relevant since operating doctrine can and does define specifically what fire support one unit commander must give and another may expect. The allocation of control of weapons systems therefore may be through organization or through doctrine. With this brief background let us now look at how the control of weapons systems is currently allocated. Since the U.S. Army has many types of missions with many organizations we can only consider a representative slice. The infantry battalion is composed of three rifle companies and a headquarters company in which the battalion organic fire support weapons are located. Now, when a battalion is assigned to a brigade, control of the fire of all weapons organic to the battalion is allocated by the division commander to the brigade commander, but the brigade commander is expected to leave the weapons organic to the battalion under the control of the battalion commander. The brigade commander may, in addition, receive the assigned support of an artillery battalion which means that artillery battalion will fire missions from the brigade commander with highest priority. The brigade commander may (and by our assumption does) allocate fires to the battalion. Note that the artillery pieces do not belong to the brigade commander, but some or all of their fires *do* belong to him. The division commander will normally have retained control of some fire support so he can influence action, if necessary, and down thru the chain of command each commander has a well defined "parcel" of control over weapons. At company level, for instance, we must consider the following potentially available types of indirect high explosive fire support as these weapons systems are currently allocated:*

Three organic platoons, each of which has six 40 mm grenade launchers.

An organic 81 mm mortar section with three mortars, forward observer at each platoon.

The battalion to which our company is assigned has a 4.2 inch mortar section with four mortars which supports our company and two others only, forward observers at company headquarters.

The brigade has one battalion of eighteen 105 mm howitzers in direct support. This battalion supports nine companies including ours, forward observers are at company headquarters.

The division has one battalion of 155 mm and 8 inch howitzers with twelve guns in general support. This battalion gives its priority of fires to the division commander but can reinforce. Fire divided among 27 companies, forward observer at company headquarters.

Corps has one armed helicopter company with fifteen aircraft, up to 150 sorties per day. Sorties are allocated to divisions, sub allocated to brigades, battalions and companies. Forward control on company radios is possible.

Corps has 90 sorties of fighter aircraft allocated daily. Sorties

*Since actual number of battalions per division, actual number of helicopters, and actual number of fighter sorties are variable this list is not actual but only typical.

are sub allocated as are armed helicopter sorties. Forward air controller at battalion level only.

Only 81 mm, 4.2 inch mortar and .85 mm howitzer, plus the 60 mm mortar system will be considered in this study because these are the weapons of interest to the Infantry Board.

CHAPTER II

LITERATURE SEARCH

The earliest attempt to apply the techniques of quantitative analysis to armed conflict was made by F. W. Lanchester (2). He theorized sets of simultaneous differential equations to describe the loss rates of opposing forces. Bonder (3) provides a thorough discussion of the implications of Lanchester's Equations of Warfare, as they are called. Most, if not all, mathematical models and simulations of combat derive from the work of Lanchester.

The first tactical simulation developed by the U. S. Army was Carmonette (4). This model was originally a platoon level model and was later expanded to be capable of handling company level problems.

Centaur (5) followed Carmonette in 1962 and was capable of handling brigade level problems. Legion (6) was aggregated from Centaur in about 1968 to simulate division level problems. Legion is, by Bonder's definition, a war game since it interfaces human players to exogenously supply key decisions. More recently Individual Unit Action (IUA) (7) and DYNTACS (8) have been introduced.

IUA is a combat simulation designed to provide a basis for comparing and analyzing the combat and cost-effectiveness of tank, antitank, and assault weapons systems. This simulation is further specialized to the extent that it portrays a battalion task force in the offense, defense, and delay, and provides an appropriate opposing force. While indirect fire support systems are not the subjects of analysis in IUA, their effects are considered through a supporting module. Since the fire support system module is only supporting, severe simplifications have been made, including limitation to preplanned concentrations only, no apparent recognition of varying weapons system capabilities, no apparatus to reflect the effects of battery dislocations and no consideration of the counterbattery role or attrition on indirect fire systems.

DYNTACS is considered to be the best combat simulation in use today and requires special discussion. DYNTACS is a general, high resolution simulation designed to support analysis of the combat performance of a battalion sized armored unit. Of specific interest in DYNTACS is an artillery module which provides indirect fire input to the general battle simulation and a new counterbattery module which subjects the original artillery module output to attrition and allows analysis of indirect fire support effects under a variety of tactics and capabilities. Together, those two modules provide a capability in DYNTACS to consider target of opportunity fires, on call fires, scheduled fires, and adjustment fires in both the fire support and counterbattery fires. The high level of resolution of the simulation allows consideration of methods of employment of counterbattery fire, specific batteries for mission assignment, assignment of priority levels, scheduled counterbattery fires and responsive counterbattery fires.

While DYNTACS has very high resolution and considers indirect fire support in an active environment where the friendly output is subject to an enemy input there are several elements of our problem to which the

DYNTACS model is not addressed. We must concern ourselves with the flow of information, ammunition, and missions in terms of response delays in order to properly answer questions about levels of control and levels of operation. Without consideration of these aspects of the problem a potentially significant factor is ignored. DYNTACS is capable of handling what are defined as "surge" situations where high levels of activity overload the mission capabilities. It handles this "surge" situation through a priority assignment routine similar to that used in actual systems.

What are the responses to delayed mission with regard to ammunition resupply, enemy troop, and weapon strength? What are the responses to delayed ammunition resupply? Most specifically can these delays be reduced by organizational changes such as level of control and level of operation. An analysis of the dynamic nature of the indirect fire support systems may shed light on these questions.

Another feature of DYNTACS that reduces its suitability is its armor orientation. Mortars are essentially infantry and anti-infantry weapons. It seems preferable that they be considered in an infantry battle environment. While this point may seem questionable to the reader untrained in tactics, it should suffice to point out that markedly different tactics and equipment must be used in different places. Infantry is not highly suited to deserts and open plains. On the other hand Armor is not well suited to mountainous or swampy terrain. This being the case, the armored battle is not the infantry battle and infantry tactics and capabilities should be viewed separately. Therefore, a simulation based on infantry doctrine organization and equipment will be better suited to consider infantry weapons and organizations.

While the above simulations seem to reflect the mainstream of quantitative analysis of armed combat, two other approaches have been pursued.

Seth Bonder in 1965 developed a kill rate probability distribution for weapons systems that adjust fire based on the results of previous rounds, as an expansion of the Lanchester attrition rate equations (9). By 1970, Bonder and Farrell had developed a set of analytical models of battalion task forces activities (10). The value of this analytical approach compared to simulation is:

1. A savings in man hours of development time and minutes of computer run time.
2. Reduced difficulty in recognizing sensitive independent variables.
3. An inherent generality which lends itself to theoretical extension.

Because of the higher efficiency of analytic models they are attracting increasing interest. Doubt remains, however, that complex systems with hundreds or even thousands of variables can be adequately modeled analytically. An alternative approach to quantitative analysis, which this study follows, is simulation through the use of special purpose languages, specifically DYNAMO. The value of special purpose languages is that they free the user from the detailed programming considerations necessary in FORTRAN or ALGOL programs. General Purpose Systems Simulation (GPSS) and DYNAMO are two special simulation languages. GPSS is primarily oriented to the queuing theory approach while DYNAMO is specifically designed to facilitate the consideration of dynamic systems.

DYNAMO was developed by Fox and Pugh (11) as a program extension of the Industrial Dynamics theories of Forrester (12). Industrial Dynamics is the application of the dynamic feedback theories of electronics to industrial systems. It should be clear that a combat problem with its tactical control, fire control, and target response feedback loops is particularly susceptible to dynamic analysis.

As might be suspected by the reader, one of the great problems in the use of simulations has been the high level of specialized knowledge necessary both to write and to understand computer simulations. Most military decision makers do not have the opportunity to learn computer programming and, conversely, skilled computer simulation personnel seldom have a thorough understanding of military tactics. The result has been a gap in understanding, exemplified by either undue confidence in, or rejection of, analysis by simulation, which has reduced the usefulness of other simulations (13). Since military decision makers require years of training and experience to reach an acceptable level of competence it would be preferable to simplify the simulation problem for use by military officers rather than try to lend combat experience, for instance, to researchers and computer personnel. DYNAMO accomplishes this to a considerable degree. Computer operating instructions are completely eliminated and relationships of the real system are represented by simple equations involving little more than addition, subtraction, multiplication, and division. Moreover, results are shown graphically.

All of the military applications of DYNAMO to date have been done at the Georgia Institute of Technology. Davis (14) used DYNAMO in the simulation of an assault river crossing problem. Faulkender (15) simulated a counterinsurgency problem. Abele (16) and Krol (17) simulated a platoon level combat situation. Abele simulated a one sided platoon defensive situation and Krol extended that model to a two sided problem which included the effects of indirect fire. Meyer (13) further expanded the same model to include movement on flat terrain and the effects of ammunition resupply. He considered only small arms in his simulation and did not consider indirect fire support.

This study is, in some respects, an extension of the work of Abele, Krol, and Meyer in that it is a DYNAMO simulation of combat at company level. In other respects, however, it is an independent simulation in that it does not consider the small arms attrition rates and it generates similar but more specialized movement variables.

CHAPTER III

OBJECTIVES AND APPROACH

Objectives

The objectives of this study are:

1. To build a dynamic model of the present indirect fire support battle system using DYNAMO and based on present organizations and doctrines.

2. To compare measures of combat effectiveness for the present organization with those of hypothetical variations.

3. To identify any related internal response changes.

Scope

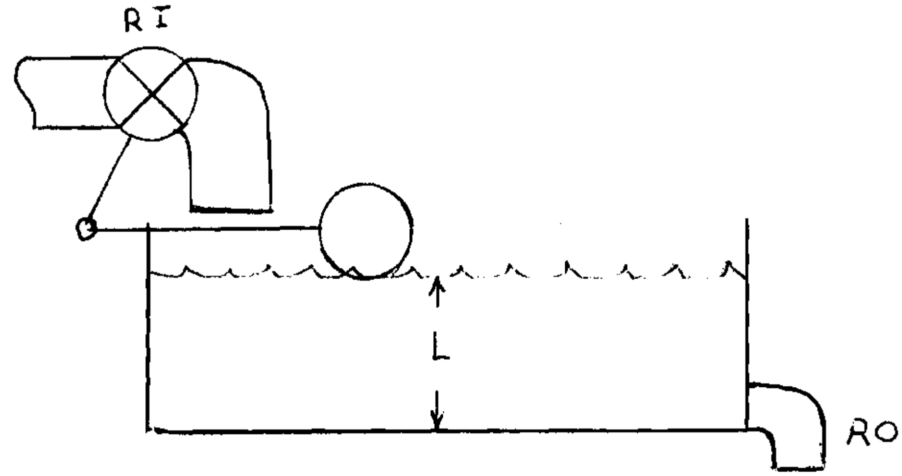
All equipment, doctrinal, and organizational data pertain to the infantry battalion operating independently. The selection of the independent infantry battalion limits the size of the study while considering all weapons systems of interest to the Infantry Board and considering the company level problem. Selection of an actual organization and mode of operation significantly reduces the number of assumptions necessary to define a closed system.

DYNAMO Modeling Procedure

The obvious dynamic nature of the fire control battle requires dynamic analysis, and the complexity of the problem suggests computer simulation rather than an analytic approach. DYNAMO is a language developed to simulate dynamic systems, but it is designed to support a specific approach, that of industrial dynamics. While this study is not intended to be an industrial dynamics study, the use of DYNAMO requires acceptance of some of the assumptions of industrial dynamics and some understanding of the concepts behind industrial dynamics. Jay Forrester, the leading exponent of this philosophy wrote, "An information feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions."(18) Thus, social, as well as physical systems can be modeled dynamically. In Industrial Dynamics, systems are composed of information feedback loops. All feedback loops are composed of levels (or accumulations), flow rates, and information. Flow rates cause accumulations to vary with time. Levels provide input to the information network and information through a decision process controls the flow rate. Thus, a reservoir with an input valve, an output valve, and a float stop on the input is diagrammed as shown in the following sketch.

In the DYNAMO diagram L is the level of the reservoir, RI is the input rate, and RO is the output rate. The solid arrows represent the flow of water. The dotted arrows represent the flow of information, from L to RI through the mechanical float device and from L to RO, because we know from physics that flow rate out is a function of head (or level). The circles with M and F represent auxiliary variables through which raw information is processed to be used in adjusting the rates. F obviously is the functional relationship between L and RO. M however is not a simple natural law. It is a relationship built to reflect the builder's desires in designing the float mechanism, and it may depend on

(a)



(b)

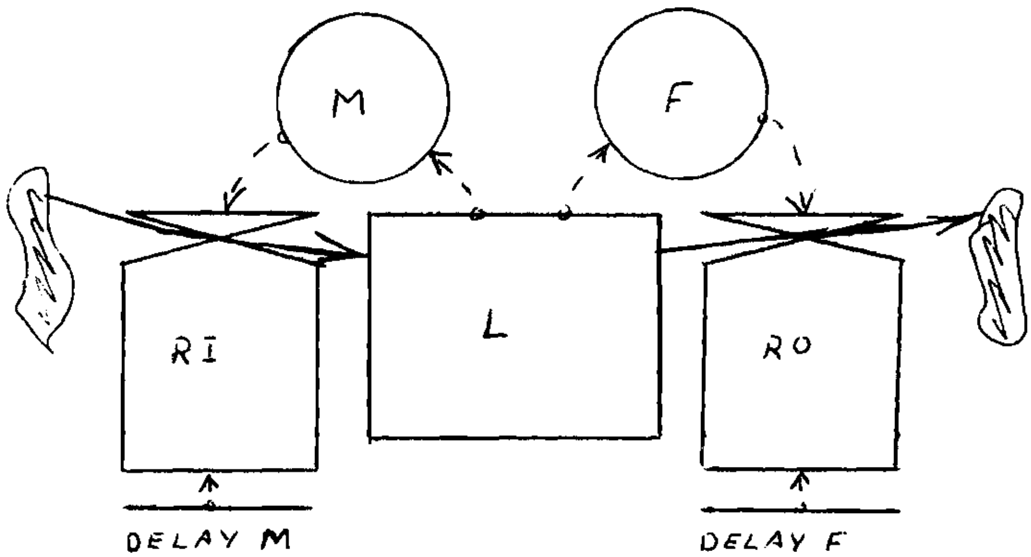


Figure 1. A Physical Example of a DYNAMO Model

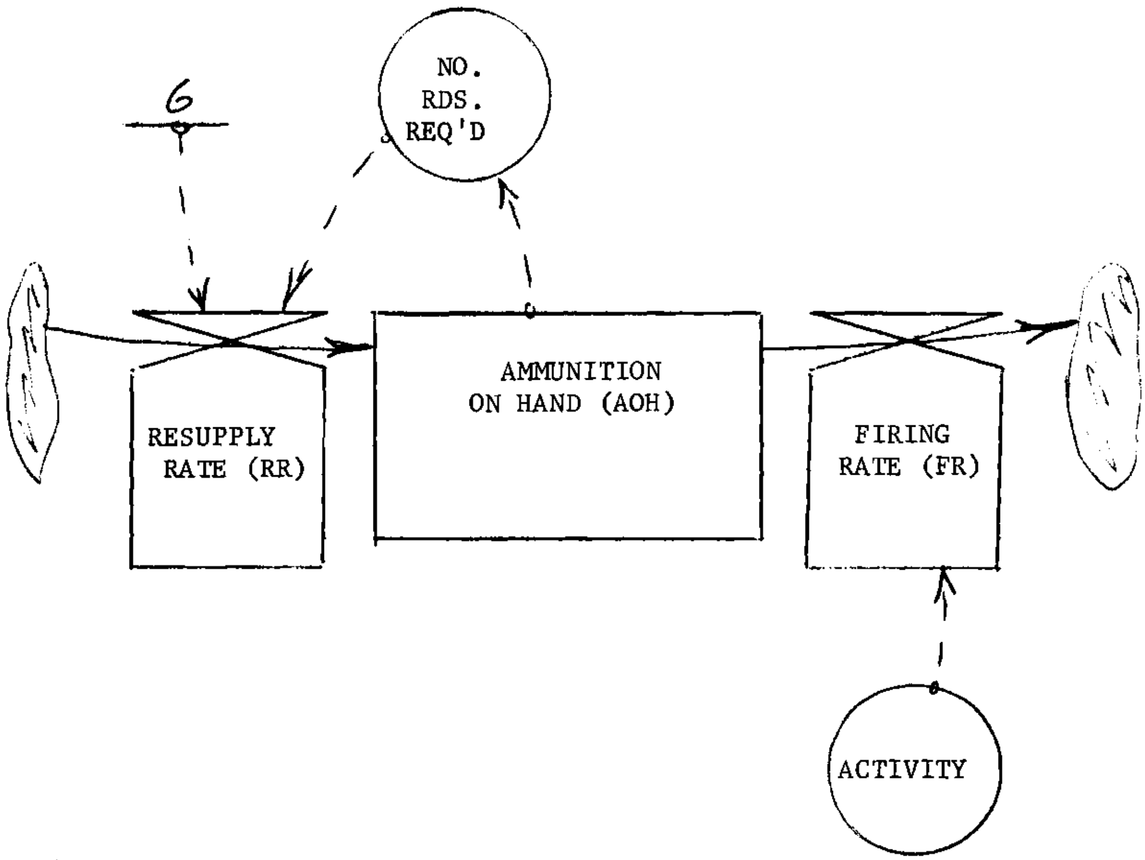


Figure 2. DYNAMO Diagram of Ammunition Supply System

information from other sources if we desire to build it that way. In any real system delays occur in the transmission of information. Flexing of the float rod and looseness of the hinge would cause delay in controlling RI for example. Delay M and delay F provide this information in the DYNAMO model.

Industrial dynamics extends this feedback concept to more complex systems, an example of which may be taken from the subject area of this study.

Suppose ammunition is supplied to the 60 mm mortar on the basis of the following decision rule: 200 rounds are requested every time the on hand level falls to 100 rounds and it takes six hours for the requested ammunition. Figure 2 is a Dynamo diagram of this system. The DYNAMO equations which represent this system to a computer are:

$$1L\ AOH.K = AOH.J + (DT)(FR.JK - RR.JK)$$

where AOH.K, a level, is the current ammunition on hand, AOH.J is the ammunition on hand at the last measurement time, DT is the time interval between measurements, FR.JK is the firing rate during the time period from J to K and RR.JK is the resupply rate during the time period J to K. FR is dependent on other factors not in this system, but let us assume FR equals 10, then

$$6R\quad FR.KL = 10$$

$$20R\ RR.KL = NRR.K/6$$

where NRR.K is the current number of rounds requested and 6 is the delay from request to receipt

NRR.K + CLIP (0, 200, AOH.K, 100)

This equation is a special function in the DYNAMO language and represents the following decision: if ammunition on hand is greater than 100 then number of rounds requested is 0, but if the ammunition on hand equals or is less than 100, then 200 rounds are requested. While this discussion has not been exhaustive, by any means, it was intended to show the assumptions of Industrial Dynamics and construction of DYNAMO.

Measures of Effectiveness

Since one of the objectives of this study is to compare measures of effectiveness among alternative organizations, any system model used must provide as output a meaningful measure of effectiveness. In defining our measure of effectiveness we must be general enough to insure that we identify the same criteria for all types of weapons under consideration. The following elements must be considered in order to meet Department of the Army requirements (19):

1. Time pattern of external input including demands and potential attack on the system.
2. The purpose of the system will be to respond to external input to the extent the system is capable. Measures of this response are measures of system effectiveness.
3. System output will be input to another system and must be sufficiently established to determine any feedback.
4. Response to input will wear out the system and cause diminished response over time.
5. When the system fails it normally becomes an input to another system which will restore capability.
6. A representation of the cyclic nature of operation may be necessary if inoperability causes backlogs.

7. When the system has failed or is busy, demands which cannot be queued may be referred to another system.
8. Operational strategies for managing the system will include alternatives of design, maintenance and employment.

These specifications are provided for Department of the Army studies to provide uniformity and the ability to interconnect where possible.

The following is a discussion of the above requirements:

1. For the general weapons system we want to develop, input to the system is some stimulation from the target system. Intuitively, this input is like an impulse because the system responds to the input and returns to a zero output state. The attack input is just one of the potential stimuli from the target system.

2. The response of the system will be limited by the following parameters, taken from Bonder (20):

Weapon aiming and ballistic errors

Target location errors

Weapon firing rate

Volley damage-pattern radius

Target distribution

Target radius

Target posture

Probability that the target is destroyed given it is covered by damage pattern.

The effects of the environment such as weather and visibility will be considered within the listed parameters. For example, the effects of weather, being unpredictable will be considered in the probability parameter.

In order to determine what may be measures of effectiveness we must first consider missions and roles. The mission of the rifle company is always to close with and destroy the enemy. The rifle company may perform this mission in several roles ranging from exploitation after a successful attack to withdrawal after an unsuccessful defense. The mission and roles may also be performed in a variety of environments in terms of both terrain and level of intensity. Now, one thing we can say without qualification at this point is that indirect fire support must contribute to the accomplishment of the rifle company mission in terms of the role and environment presently occupied by the supported company. To do otherwise is clearly purposeless from our point of view. How does indirect fire support contribute to accomplishment of the rifle company's mission? The man who actually puts fire support for the rifle company to work is the rifle company commander and he is taught to use indirect fire support in four ways:

a. As a portable obstacle to deny terrain or routes to the enemy.

b. As a shield to suppress enemy fire.

c. To return fire on enemy indirect fire weapons (counterbattery fire).

d. As a source of firepower to destroy the enemy.

In the rifle company's mission we can see two distinct elements: 1) close with the enemy and 2) destroy him. These represent two of the three essentials of all combat organizations which have been emphasized by military philosophers and tacticians, at least since Napoleon. The popular phrase is "Shoot, move, and communicate." The requirement to communicate is not explicit in the company's mission statement, but is implicit in its organization and we shall have to consider it as an implicit part of our system simulation.

The four uses of fire support rather clearly fall into one or the other of the remaining two essential capabilities. The first two uses contribute to the ability of the rifle company to move or close with the enemy and the last two uses clearly contribute to the ability to destroy the enemy. Following this analysis and Quade (21) there are two criteria for the effectiveness of fire support weapons systems. Let us call one of them the target destruction criterion and the other the maneuver support criterion.

The structure of DYNAMO leads us to what must be a good and direct measure of effectiveness with respect to the target destruction criterion, the enemy troop strength. Enemy troop strength is obviously a level and must directly reflect the ability of the system to meet the destruction part of the rifle company mission.

When indirect fire support weapons systems are acting in maneuver support, rounds are simply fired to impact at a specific location, and the wider and more dense the obstacle made, the better. Hence, this is a simple role to handle. Three parameters obviously apply: range, accuracy, and effective bursting radius. If the system cannot reach the target location it has no value in this role, but if range is sufficient then the value of the system is then a function of the accuracy (dispersion pattern), effective bursting radius (width of obstacle), and sheath size (length of obstacle). Range acts on this measure of effectiveness in a yes or no manner then, and width and accuracy act by multiplying together since simultaneous density and width are required.

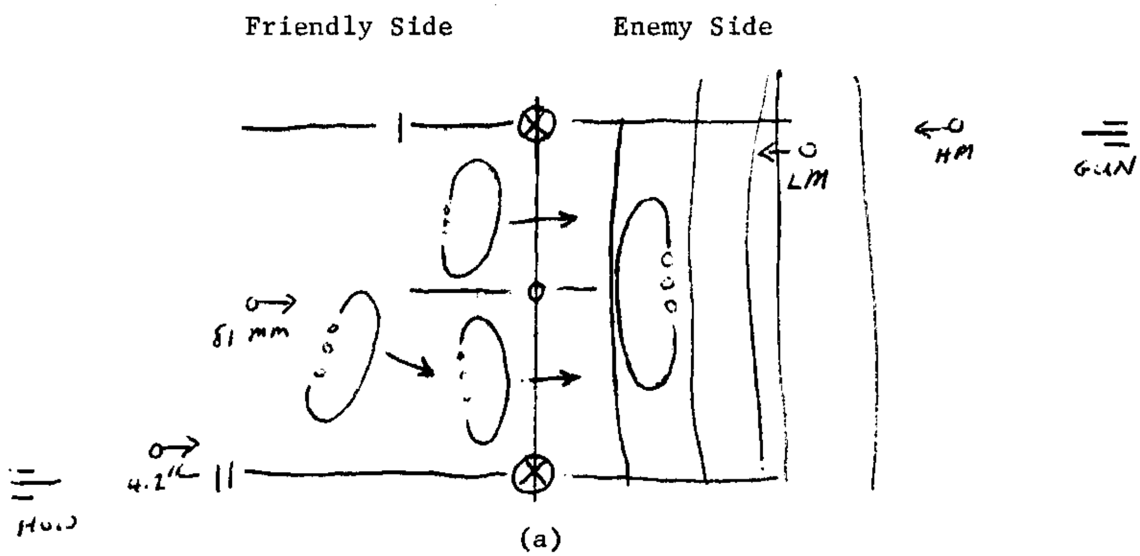
CHAPTER IV

DESCRIPTION OF THE PROBLEM

In order to meet the objectives of this study the combat situation is perceived as a closed system at battalion level. Because the rifle company commander is at a level where decisions regarding all of the weapons systems are made, the system will be viewed from his point of view. The indirect fire support elements of an infantry battalion are engaged in combat to support the activities of the rifle company commander and they are available to him in the following strengths and at the following levels (22): 60 mm mortars are not now in use in infantry battalions. They were used at company level before the 81 mm mortar was standardized as the company level indirect fire weapon. Each company has three 81 mm mortars under its own control. The battalion has four 4.2 inch mortars which support two companies in contact with the enemy. The battalion is supported by six 105 mm howitzers which support two companies in contact.

The enemy force is supported by a varying number of weapons dependent on the role. If the enemy force is attacking, then it is supported by eighteen light mortars at company level with six heavy mortars and six gun-howitzers at battalion level. If the enemy is defending, however, then he is supported by only six light mortars at company level with six heavy mortars (23). These tactical situations are depicted at Figure 3.

The combat action which we will model occurs as follows. To initiate action let us assume that the friendly side orders a fire mission on



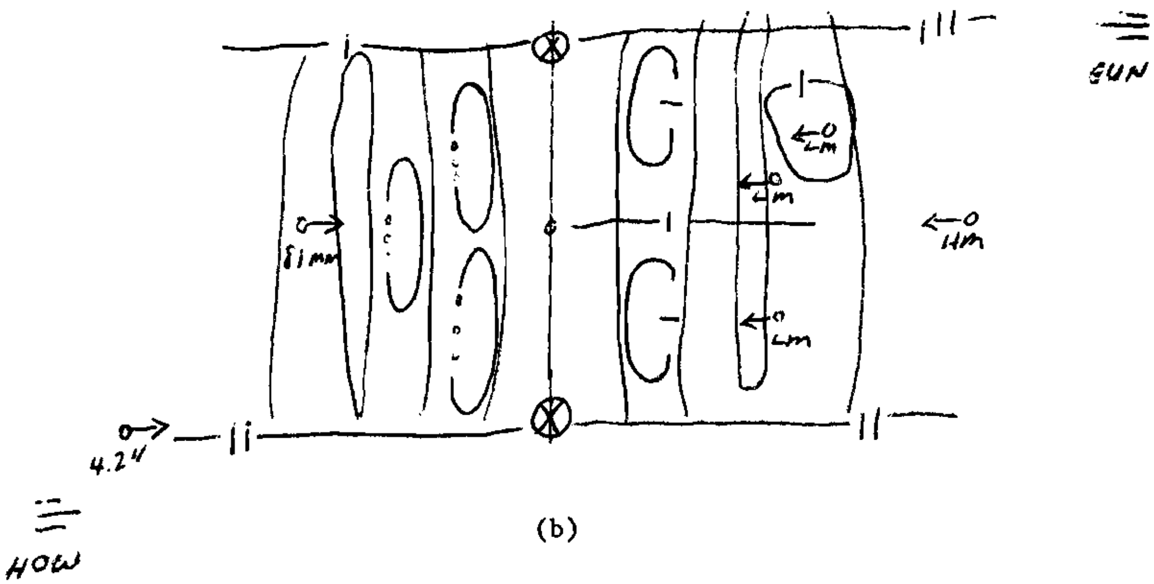


Figure 3. Assumed Tactical Situation
(a) Friendly attack
(b) Friendly defense or delay

the suspected location of the enemy force. That mission is initiated with a period of fire adjustment and when the adjustment rounds are impacting on the intended target location the mission is completed with one or more volleys. During the period of adjustment any enemy troops in the area take warning and cover and the enemy force begins to make a response. If the target location is occupied by the enemy, and if any troops are caught in exposed positions, then the enemy troop strength is reduced. An appropriate reaction in this example would be for the enemy indirect fire weapons to fire on the initiating friendly indirect fire weapons. If this fire is effective, then there will be fewer friendly indirect fire weapons. At this point one cycle is completed and the second cycle may be initiated by the friendly force or action may be terminated. If action is continued, the target now may be the suspected troop location or it may be the enemy weapon position. The results of the cycle we just considered are a depletion of both friendly and enemy ammunition on hand and, depending on whether hits occurred or not, a depletion of enemy troop strength and friendly weapons strength. Now, since riflemen (troops) are never within range of indirect fire weapons (or should never be as long as normal operating rules are working) a troop loss will have no effect on the next cycle, but the ammunition expenditure, if not replaced, will eventually stop action and the loss of an indirect fire weapon decreases the effectiveness of the firing unit and hence, in future cycles, the opposing troop loss rate will be lower and the opposing troop strength levels will not fall as much in future cycles.

We assumed an initiating mission to start our example, but the real system starts on real events not assumptions. These real events are the results of tactical decisions such as the decision to attack, and the action resulting from these decisions are planned missions as opposed to missions against targets of opportunity.

Let us now trace the flow of information and action carefully through all the significant elements. Figure 4 shows the flow of information in combating systems in the action described above. Let us assume that action starts with some act (attack, withdrawal, resupply, etc.) by the enemy troop target. This is observed by the friendly force (friendly troop target (rifle company)) and generates a fire mission. The fire mission is transmitted to the friendly fire control element. This may be nothing more than the forward observer if the weapon system is organic to the company, otherwise it may expand to a sizeable organization with decision makers at several levels of command. This fire mission is either transmitted to the friendly fire support unit or assigned a priority and held by the fire control element until it can be completed. If demand is high from a company with an initially low priority then the priority may be shifted. Once the fire mission is transmitted to the friendly fire support unit, it is converted into rounds of ammunition and fired. This process involves adjustment and, hence, the information loop is repeated several times in each mission. The firing of ammunition generates two flows of information. An attack input is delivered to the enemy troop target and a resupply input is delivered to the friendly resupply element. The attack input to the enemy troop target stimulates the enemy troop target to respond. This may be with either counterbattery fire on the weapon actually delivering rounds or it may fire on the friendly troop target.

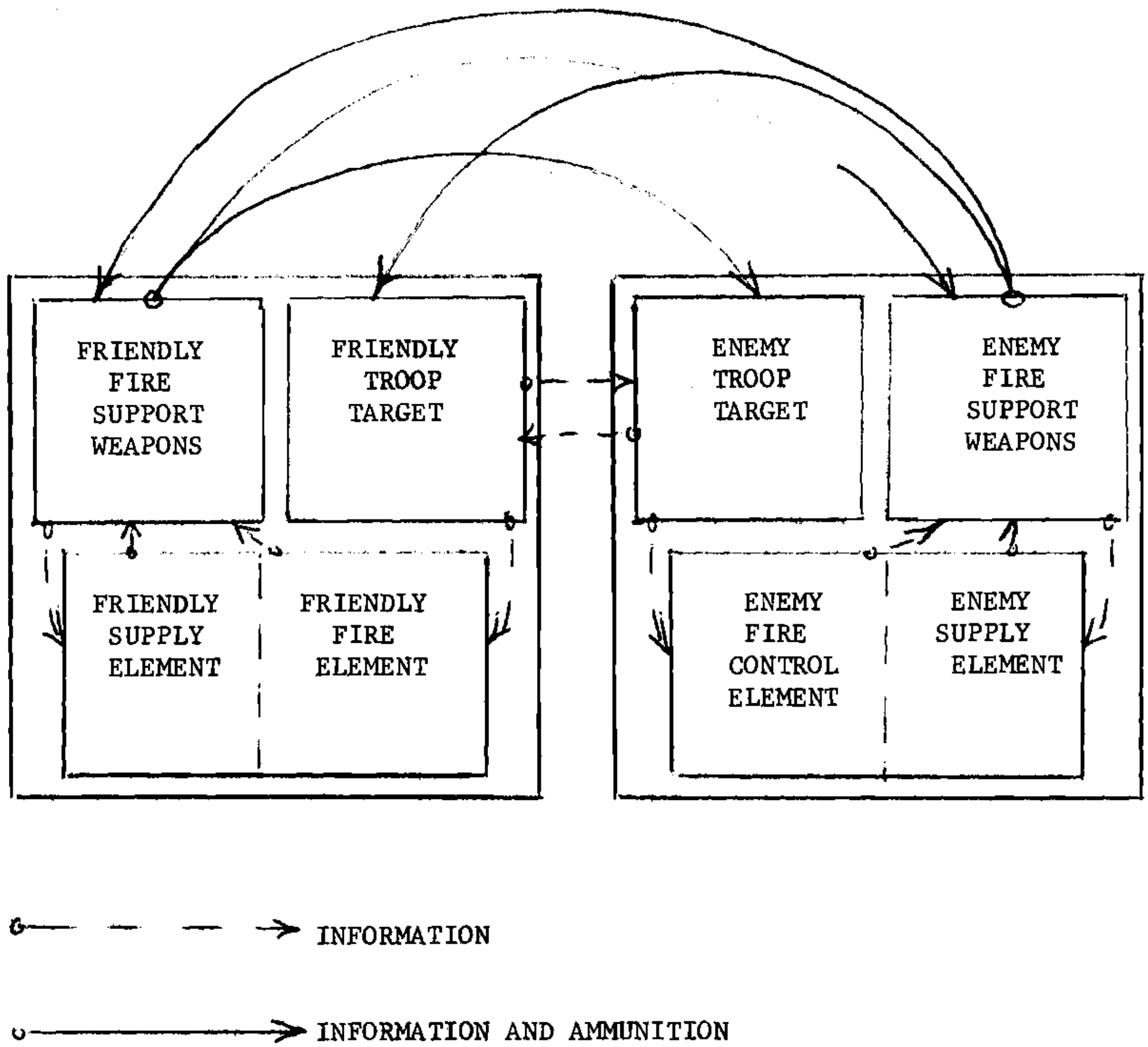


Figure 4. Information Flow Among Fire Support Elements

In either case the impacting friendly rounds stimulate an information flow in the enemy system identical to that in the friendly system. This information flow is depicted in Figure 5 in terms of levels, auxiliary functions and information flow. In this diagram troop and weapons strength levels are controlled by the opposing mission effectiveness. Mission effectiveness is controlled by the mission level, mission potential, and target activity level (through exposure). The mission level is controlled by the opposing unit activity level, but the mission potential is controlled by terrain and movement data, ammunition level, unit activity, and weapon strength level.

A discussion of the choice of flow elements to describe the problem is in order at this point. From the point of view of dynamic theory we could as easily build our analysis in terms of the flow of rounds of ammunition, pounds of explosive or missions. A mission is far from a standard measure since missions vary extensively in terms of time, number of rounds and targets, therefore it would seem at first glance that the mission is not a very good unit of flow. The fire mission was chosen as the element in flow because we are inquiring into the effects of organizational structure on the effectiveness of the fire support system and the fire mission is an organizational weapon designed for use on an opposing organization. That is, one fire mission can always be equated to one target and, equally important, to one firing unit in a given time interval. Obviously the comparative cost among missions will require some common measure, but this common measure will not reflect the interaction between weapon and target we seek to analyze. The concept of a fire

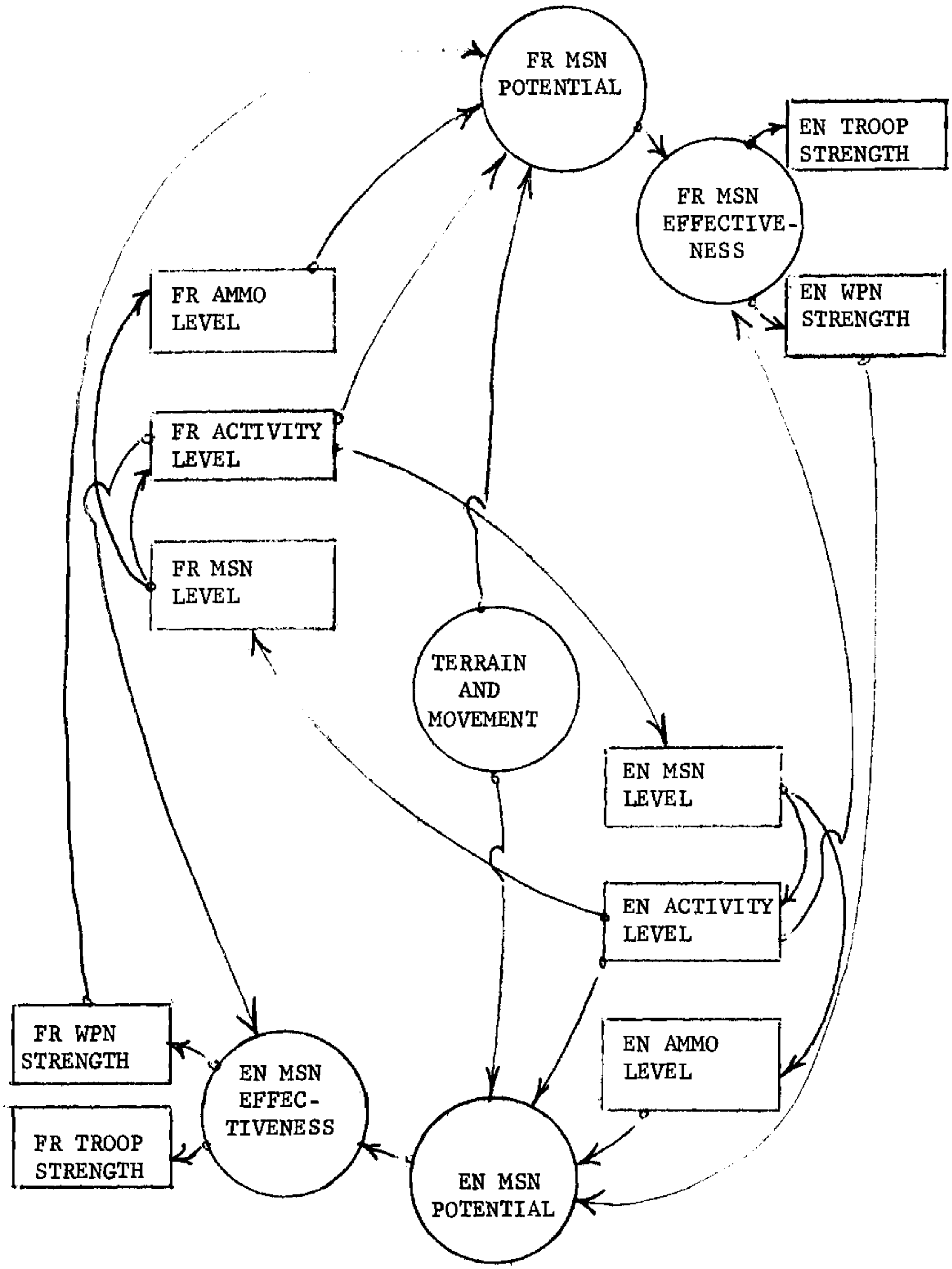


Figure 5. Principal Feedback Loops in an Indirect Fire Support Battle System

mission does include the time delay events that contribute to interactions, (e.g., adjustment delay gives warning and protective reaction time to the opponent). Hence the most appropriate flow element around upon which our analysis can be made is the fire mission.

A highly significant factor in the effectiveness of any weapon system, and particularly indirect fire weapons systems, is the random nature of the fire control process. So many unpredictable elements such as weather, temperature, enemy activity, and enemy location bear on the effectiveness of indirect fire support that randomness must be considered. These probabilistic elements are not reflected in the previous diagram because they are an internal part of mission effectiveness.

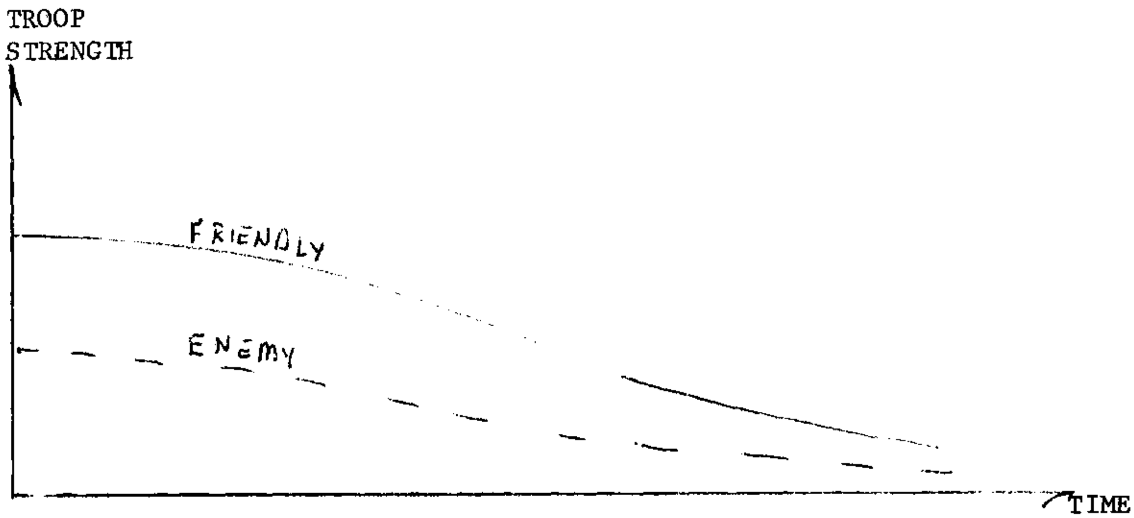
Following Bonder's development of the probability of a target hit, $P(K|H)$ and his discussion of its extension to area fire weapons, it seems conceptually correct to describe the probability of target destruction for the indirect fire support weapons as the conditional probability of a target kill given a hit on the target area and given that the target area is occupied, $P(K|H,T)$. The probability of a hit is dependent on weapon aiming and ballistic errors, target area location errors, and volley damage pattern radius. The probability that the target area is occupied is dependent on the type of mission being fired, target distribution, and the time delay from first round impact to target hit. This time delay in turn is a function of weapon firing rate (including adjustment time) and the number of rounds fired in adjustment. The probability of target destruction is dependent on the first two probabilities and on target radius and target posture.

Since this is true of both friendly and enemy systems, and in a closed system the enemy kill rate will equal the friendly loss rate, the ratio of friendly to enemy kill rates reflects the system's ability to destroy assigned targets while itself surviving.

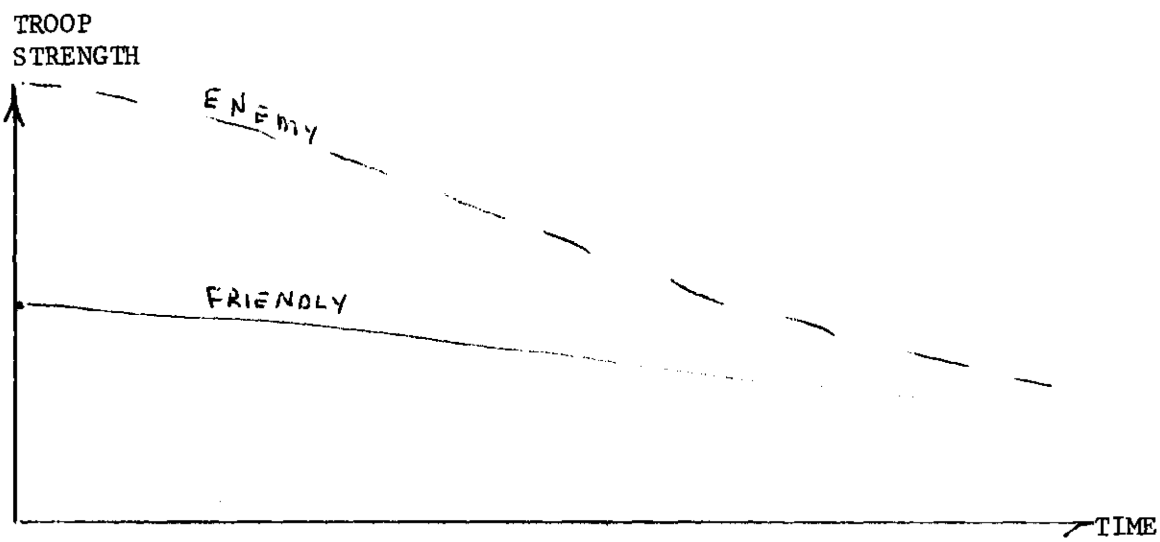
If we knew, somehow, that these three probabilities were independent of each other, then the probability of target kill would be easily found as the product of the three probabilities. There is no good reason however, even to assume independence among these probabilities in the real system, and the analytic solution is therefore extremely complicated as evidenced by Bonder's work. Fortunately, we need neither assume independence nor analytically solve a complicated probability statement. The nature of both the DYNAMO and the real system suggest that troop strength levels are appropriate measures of effectiveness for weapons designed to destroy personnel. Now, this troop strength level will be controlled by a loss rate which, in turn, will be dependent on other levels and rates, such as troop exposure, enemy mission arrival rate, etc. Thus if the appropriate probability statements are applied at the appropriate place within the system and the system is correctly modeled, then any dependence among the three probabilities we have discussed will be generated by the information feedback inherent in the DYNAMO model.

If this description of the problem is correct then behavior of the model, as reflected by troop strengths should be continuously decreasing, but at varying rates. In the case of the friendly attack friendly losses should be greater than enemy losses, but friendly strength should still exceed enemy strength when the enemy force is forced to withdraw.

When the friendly force is defending the same relationship should occur between attacker and defender. The predicted behavior of the system is depicted in Figures 6a and 6b.



(a) FRIENDLY ATTACK



(b) ENEMY ATTACK

Figure 6. Predicted Model Behavior

CHAPTER V

THE MODEL

In this chapter the construction of the simulation model will be discussed. Because this system is somewhat complex, we will attempt to maintain clarity by discussion in sections. First, the general system will be described in terms of levels, rates, and generalized auxiliary functions. Following the development of an overall outline of the model, details will be added by section and finally a complete diagram will be presented. In order to reduce the complexity of the discussion, the DYNAMO equations will be appended rather than presented in this chapter. Because the structure of the two sides is nearly identical, clarity can be further enhanced by discussing only half of the system and then discussing only significant differences between the two sides later.

The General Structure

Because we want to analyze the friendly force, we will develop that half of the battle system. This general structure is simply half of Figure 5 converted to DYNAMO symbols. In Figure 7 all symbols have been designated as friendly or enemy. From this point on, however, we will omit that distinction unless it is essential to clarity. As the diagram shows, each side is composed of five subsystems: a weapons strength subsystem, a mission flow subsystem, an activity subsystem, an ammunition flow subsystem, and a troop strength subsystem. In addition to these are

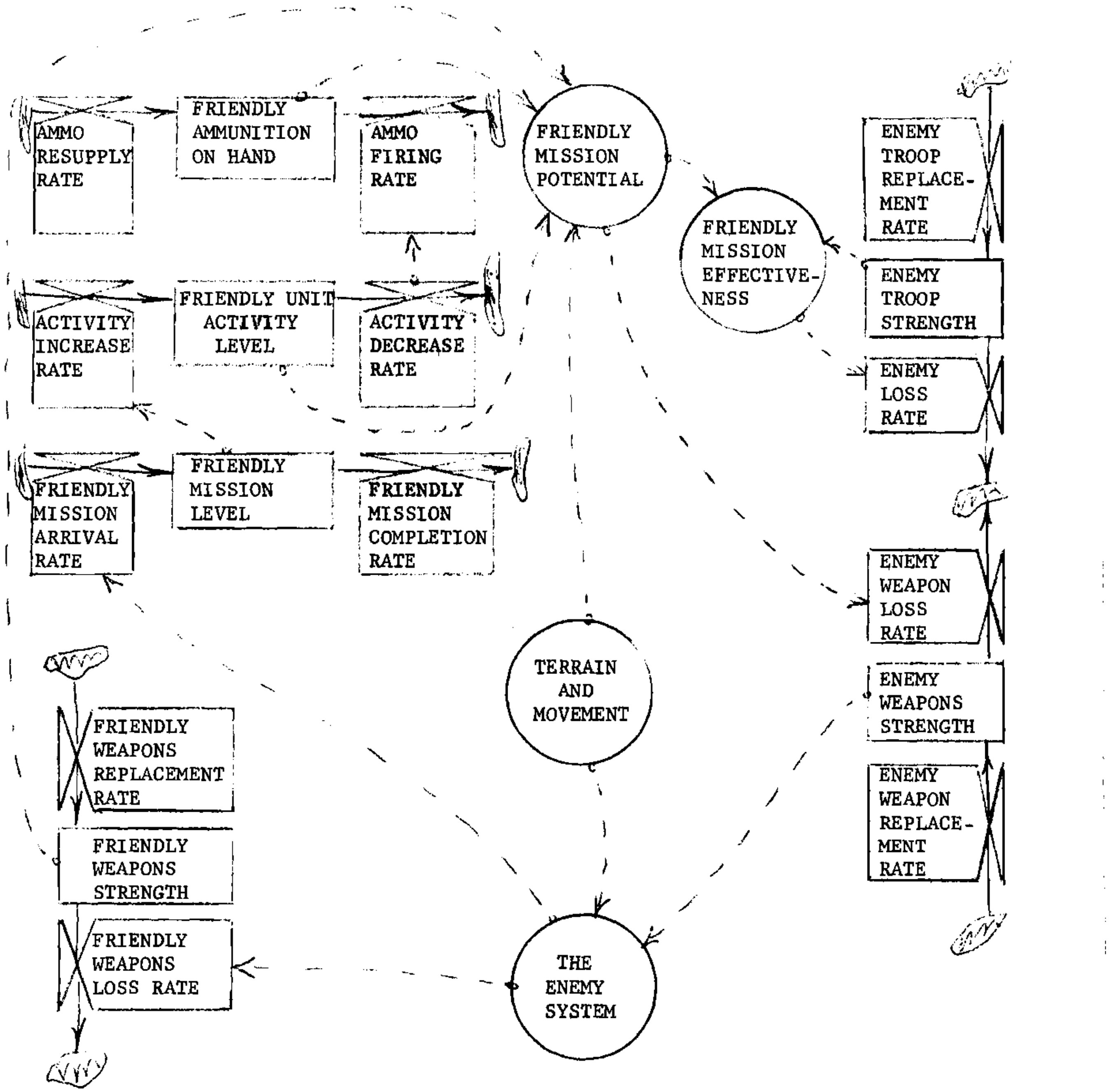


Figure 7. General Structure of the Model
(Friendly Side Only)

the decision links and environment factors represented by the three auxiliaries shown. To close the loop the entire enemy system except enemy troop strength and weapon strength is shown as a single symbol.

To discuss the detailed construction of the model, we will first describe each subsystem and then we will describe auxiliary decision making sections.

The Subsystems

Mission Flow

The general structure diagram shows mission flow in terms of one level and two rates, but the mission flow subsystem is more complex than that. Because several other subsystems are dependent on differing outputs from this subsystem, several levels must be defined. The target responds to the missions delivered. The ammunition subsystem also responds to the mission delivered in terms of ammunition expended. The unit activity subsystem responds to both the number of missions in progress and the number of missions waiting to be processed. Therefore, this subsystem consists of three levels, the mission backlog level (FMB), the missions in progress level (FMIP), and the missions delivered level (FMD). Controlling each level is a rate with decision and delay input for each. The mission flow subsystem is shown in Figure 8.

The mission arrival rate (FMAR) is controlled by enemy unit activity (EUA) and friendly plans (PFM). Since missions are conceptual rather than physical, their arrival is not measurably delayed so the delay shown here is DT the measurement time interval. The mission acceptance rate (FMACR) depends on the number of missions in progress (FMIP), the

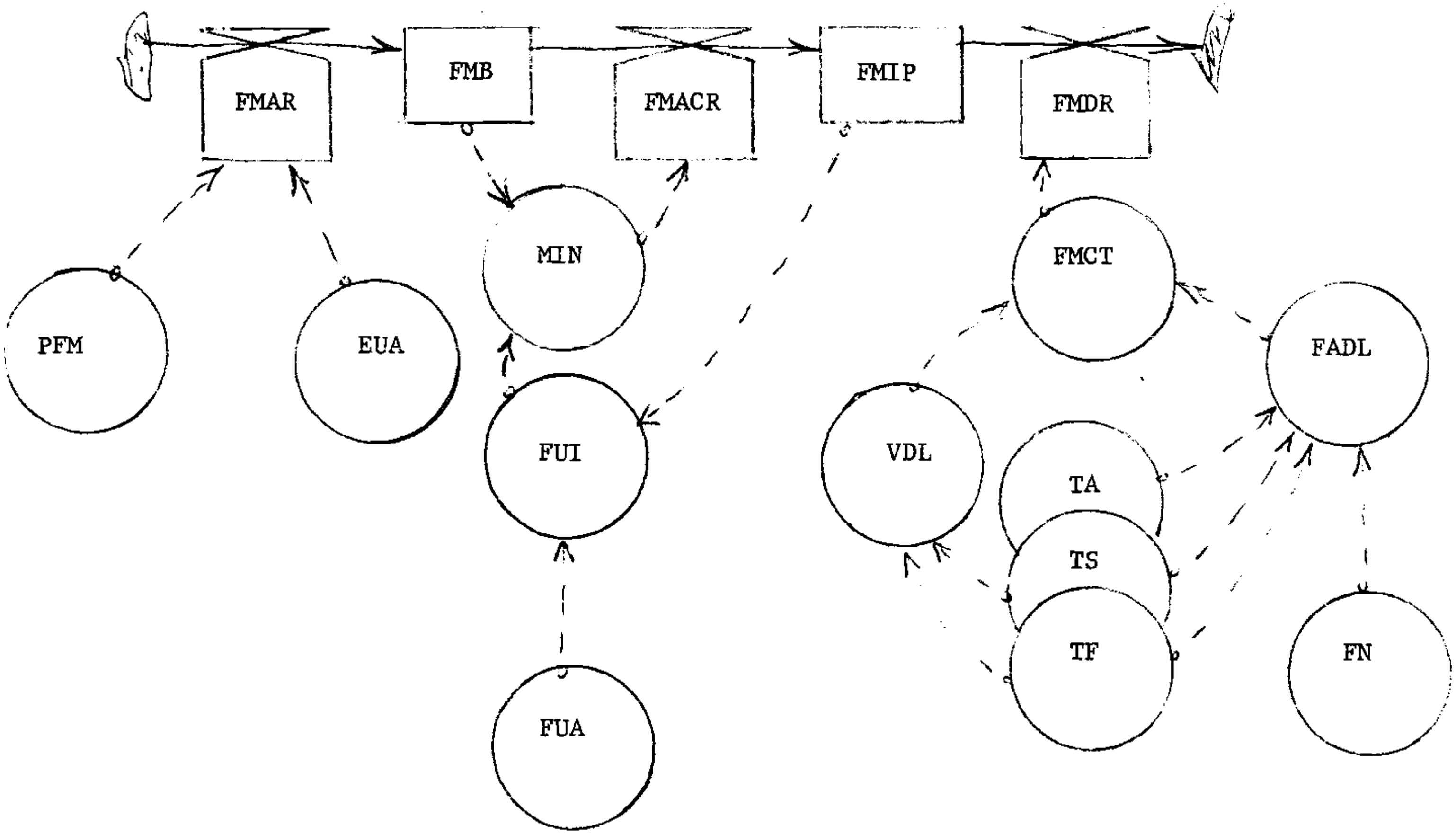


Figure 8. The Mission Flow Subsystem

assigned priority levels as reflected by the friendly unit activity level (FUA), and the number of missions awaiting acceptance (FMB). The difference between the number of missions the system can accept (FUA) and the number of missions in progress (FMIP) is compared with FMB. The mission acceptance rate is the lesser of the two.

The mission delivery rate (FMDR) is dependent on the number of missions in progress (FMIP) and the mission completion time (FMCT). The mission completion time is the sum of the adjustment time (FADL) and the volley delivery time (VDL). For simplicity it is assumed that each mission contains only one volley and a volley consumes the time to serve the weapon (TS) and the time of flight (TF) so VDL equals TS plus TF. The adjustment time includes TS, TF, and adjustment time (TA), and the sum of these is multiplied by the number of rounds (FN) which must be fired to adjust the weapon onto the target. Because of lack of data, it is assumed that no more than five rounds will be required in adjustment and the distribution of FN is assumed to be as shown in Table 1.

Table 1. Assumed Distribution of FN, the Number of Rounds to Adjust

X	P(FN ≤ X)
1	.116
2	.234
3	.260
4	.260
5	.130

These assumptions are based on the combat experience of the author and are believed to be reasonable approximations. The DYNAMO equations for this subsystem are shown in Appendix A.

Ammunition Flow

The ammunition subsystem must be expanded but in a different way from that of the mission subsystem. Only the ammunition on hand level provides input to another part of the system, but because there are four different weapons in the system there are four different types of ammunition to consider. Hence, we must expand the ammunition flow section to include four ammunition subsystems. Since they are all structured identically, we need not develop each separately. For clarity we will develop only one example of the ammunition subsystem.

The ammunition on hand level for each weapon type is controlled by an ammunition firing rate (FAF) and an ammunition resupply rate (FAD). The expenditure is controlled by the mission completion time (FMCT) and the number of adjustment rounds (FN) from the mission flow subsystem and the number of weapons firing (WSH) which will be developed later in the mission potential section. Since there are four separate ammunition subsystems, they are identified by number (e.g. FAF60, FAD60, etc.). Resupply of ammunition may follow several inventory policies. For the model, it is assumed that resupply is by request and a request is submitted when the on hand level reaches a preselected level. A substantial delay occurs between request and delivery due to transportation delays. This is reflected by the DELAY 3 symbol, a special function of DYNAMO which causes a third order delay based on a total delay time (6, in this case) and an initiating rate (FAR60) which is the ammunition requesting rate. The DYNAMO equations for these subsystems are shown in Appendix B. Figure 9 is a diagram of the ammunition flow subsystem.

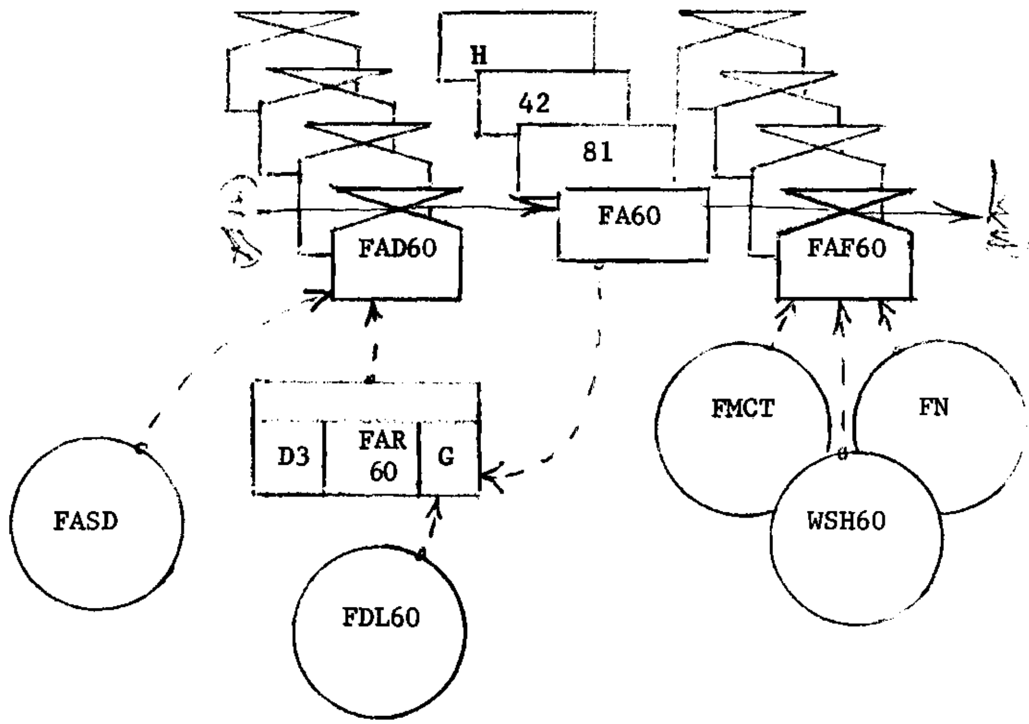


Figure 9. The Ammunition Flow Subsystem

Unit Activity Level

This subsystem reflects the level of activity in terms of the number of indirect fire support units committed to support of our subject company. The activity level (FUA) is controlled by an input rate (FUAI) and an output rate (FUAO). Because a priority change for each weapon requires a decision at the level of control for that weapon, a delay occurs. The higher the echelon of control, the longer that delay will be, because each next higher level must wait while the lower evaluates the information. Thus, if a weapon is controlled at brigade level, for example, the time delay from occurrence of a need for a priority switch and the switch includes time for the company to evaluate the need and forward a request to battalion level and time for battalion to do the same thing. Priorities are not automatically switched, of course, because the requesting unit may not need the support as much as another unit. For this model we will assume that the switch does occur in every instance. We can do this because we are interested in comparing effectiveness of mixes and this comparison is valid in the unit under attack, hence this assumption should not detract from the value of the model.

The activity increase rate depends on the difference between the present activity level and the mission backlog, but if the activity level is already four, indicating all units are committed, then there is no level increase allowed. The activity decrease rate is simply the reverse of the increase rate. In either case the rate is 1, with a delay of approximately ten minutes. Figure 10 shows the unit activity level subsystem. The DYNAMO equations for this subsystem are shown in Appendix C.

Weapons Strength Level

Any given enemy mission will be directed against one target. This target may be enemy troops, it may be a place on the ground (in the case of denial and suppressive missions), or it may be an enemy indirect fire weapons site. It would be nearly impossible to simulate the real decision process which would select targets because questions of priorities, perceived threats, and detailed friendly intentions, among others, would have to be answered. Such resolution is far beyond the capabilities of other sections of this simulation so a drastic approximation will be made. First, we will assume that none of our missions is a maneuver

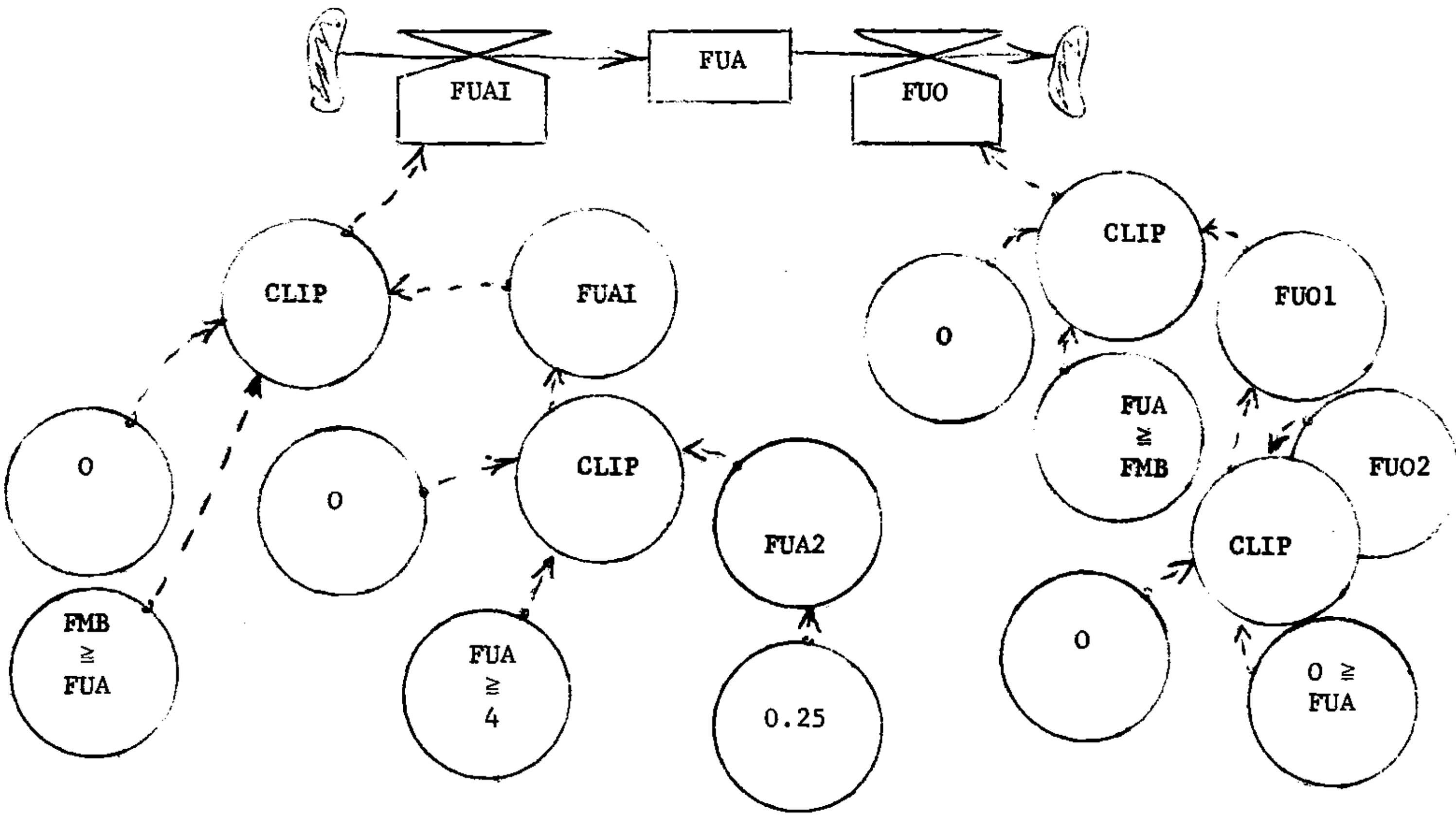


Figure 10. Unit Activity Level Subsystem (FUA)

support mission. Thus, every mission will either affect the enemy troop strength or enemy weapons strength. This assumption will have cost us no loss in information because the current friendly mission potential (FMP) tells us all we need to know to compare the maneuver support ability of various mixes for a given mission.

An assumption which will cause a loss of information, however, is the method of choosing between troop and weapon targets. Rather than attempting any of the complex logic involved, we will simply assume that every fifth mission is a counterbattery mission. The choice of one mission in five is purely arbitrary, since no data has been found on the actual frequency of counterbattery and antipersonnel missions.

Friendly weapons strength (FWS) is an auxiliary variable composed of the strength levels for each of the friendly weapons systems.

$$FWS = TSH60 + TSH81 + TSH42 + TSHH$$

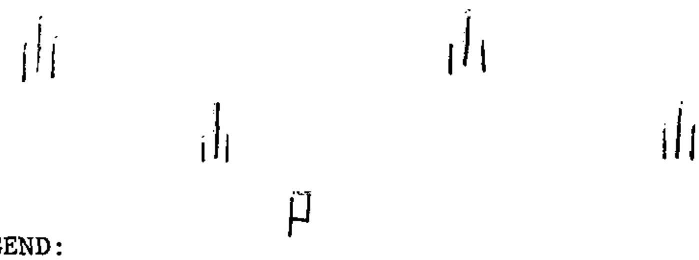
where TSH60 is the current number of operating 60 mm mortars, TSH81 is the current number of 81 mm mortars, TSH42 is the current number of 4.2 inch mortars, and TSHH is the current number of howitzers.

These weapons strengths are controlled by loss and replacement rates, for example, the 60 mm mortar loss rate (L60R) and the 60 mm replacement rate (R60R). Because only one weapon site will be fired on at a time, we must select the target as well as consider a probability of weapon kill. Hence, a friendly weapon loss rate (FWLR) is defined. FWLR is the current general weapon loss rate and one of the four friendly weapons will be selected to equal FWLR. The rule by which this decision is made is: That weapons site which fired the most rounds in the period JK is the selected counterbattery target. This rule is used because counterbattery fire is assumed to be based on the output of a countermortar radar set and the target it is most likely to find is the target which puts up the most rounds. The same decision process determines R81L, R42L, and RHL. At the same time, the same decision criteria are used to determine whether or not the target location is the 60 mm mortar site, the 81 mm mortar site, the 4.2 inch mortar site, or the howitzer site. While this decision is made in the movement section, we will mention it here since it is essential that the choices be exactly parallel.

So far we have defined the decision rule for firing a counterbattery mission and the decision rule for picking the target site and target weapons strength level. It remains to determine whether or not a weapons loss will occur.

Just as the troop loss rate will include random variables based on weapons accuracy and adjustment delay time, the weapons loss rate includes a random variable. The weapon accuracy is still random, but more important, the counterbattery mission is normally unobserved. Only the countermortar radar data are available. We can consider that each firing site consists of the weapons and a fire control center. These elements are always separated enough to insure one hit will not destroy two elements. Therefore, we can approximate this target with a series of points, one for each weapon plus one for the fire control center. Since these positions are normally unprotected, any impact within the effective bursting radius for the round fired of a weapon will cause destruction.

Let us assume for simplicity that, if a hit occurs, it will involve only one weapon. A typical disposition of a four weapon battery is shown in Figure 11 where the weapons are separated by their own effective bursting diameter to improve the effectiveness of their own sheath.



LEGEND:

represents weapon location

represents the fire control center location

Figure 11. Typical Battery Disposition

Now countermortar radar might choose any of the weapons as the target center so the enemy sheath may be centered on any of the four target weapons and it would seem that all friendly weapons are equally likely to be target center. If we define the counterbattery target to be the area which includes all rounds likely to be fired on radar information, then we can approximate the probability of a hit with the ratio of the area covered by the friendly sheath to the target area. The friendly sheath area is the number of weapons firing (FWSH) times the area included in one average burst (FEBD) and the target area is approximately twice the area of the target sheath plus the area of the firing sheath. The depth of the target area will be approximately twice FEBD because weapons are usually sited in depth to reduce the hit probability, see Figure 12.

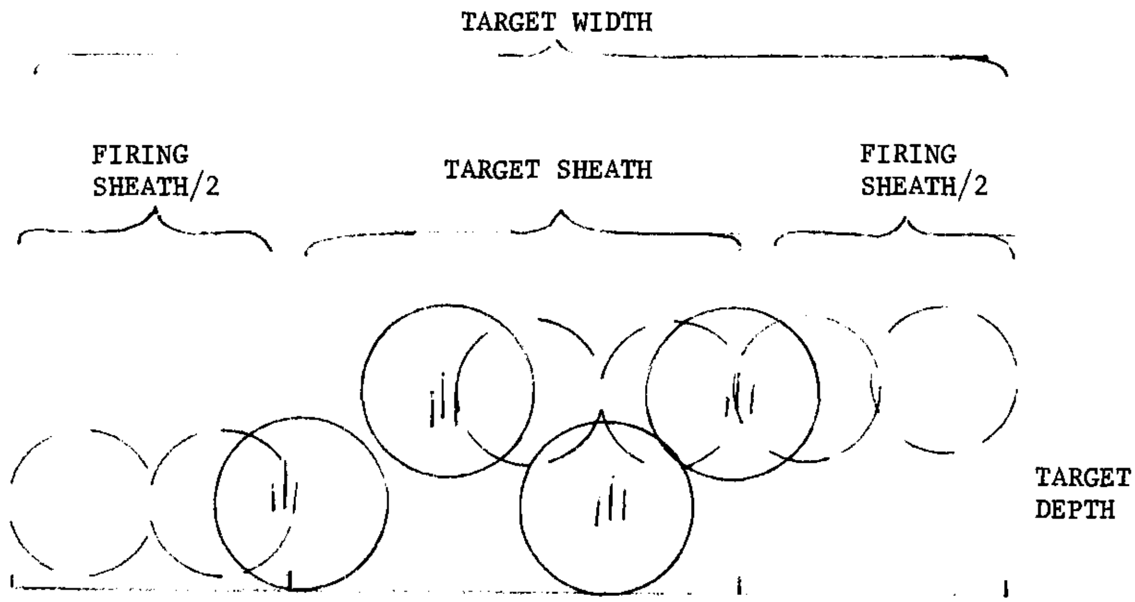


Figure 12. Approximation of Counterbattery Target Area and Firing Sheath Area

So, by our assumptions, the weapons loss rate (FWLR) equals zero or one at any given time, depending on the probability of a hit. This probability is simulated by comparing the approximating probability ratio with a random number of uniform distribution from zero to one. If the random number is less than the ratio value, then a hit is assumed and FWLR equals one.

Since the target area equals the firing sheath area plus the target sheath area multiplied by two, the ratio can never exceed one. It must be noted in the above discussion that no consideration of personnel casualties due to counterbattery fire was made. This is considered beyond the appropriate resolution level for this simulation since personnel serving indirect fire weapons are part of the indirect fire system and are not troops in the sense that they can hold ground, attack, or delay. The remaining variable in the enemy weapons strength subsystem is the enemy weapons replacement rate (FWRR).

Let us assume FWRR equals the friendly weapons loss rate, delayed by the time necessary to bring a replacement weapon up to the firing site. This delay will vary because of many factors, but let us assume it takes 12 hours to bring up the replacement weapon. The application of FWRR to the appropriate weapon strength level follows the same decision rule as for the loss rates. The DYNAMO equations for this subsystem are shown in Appendix D, and Figure 13 is a diagram of this subsystem.

Troop Strength Level

Enemy troop strength (ETS) is also a level or accumulation. It is the troop strength from the previous measurement time plus replacement and minus losses during the intervening time periods, as shown by the following equation.

$$ETS.K = ETS.J + (DT)(ETRR.JK - ETLR.JK)$$

Figure 14 is a diagram showing the enemy troop strength.

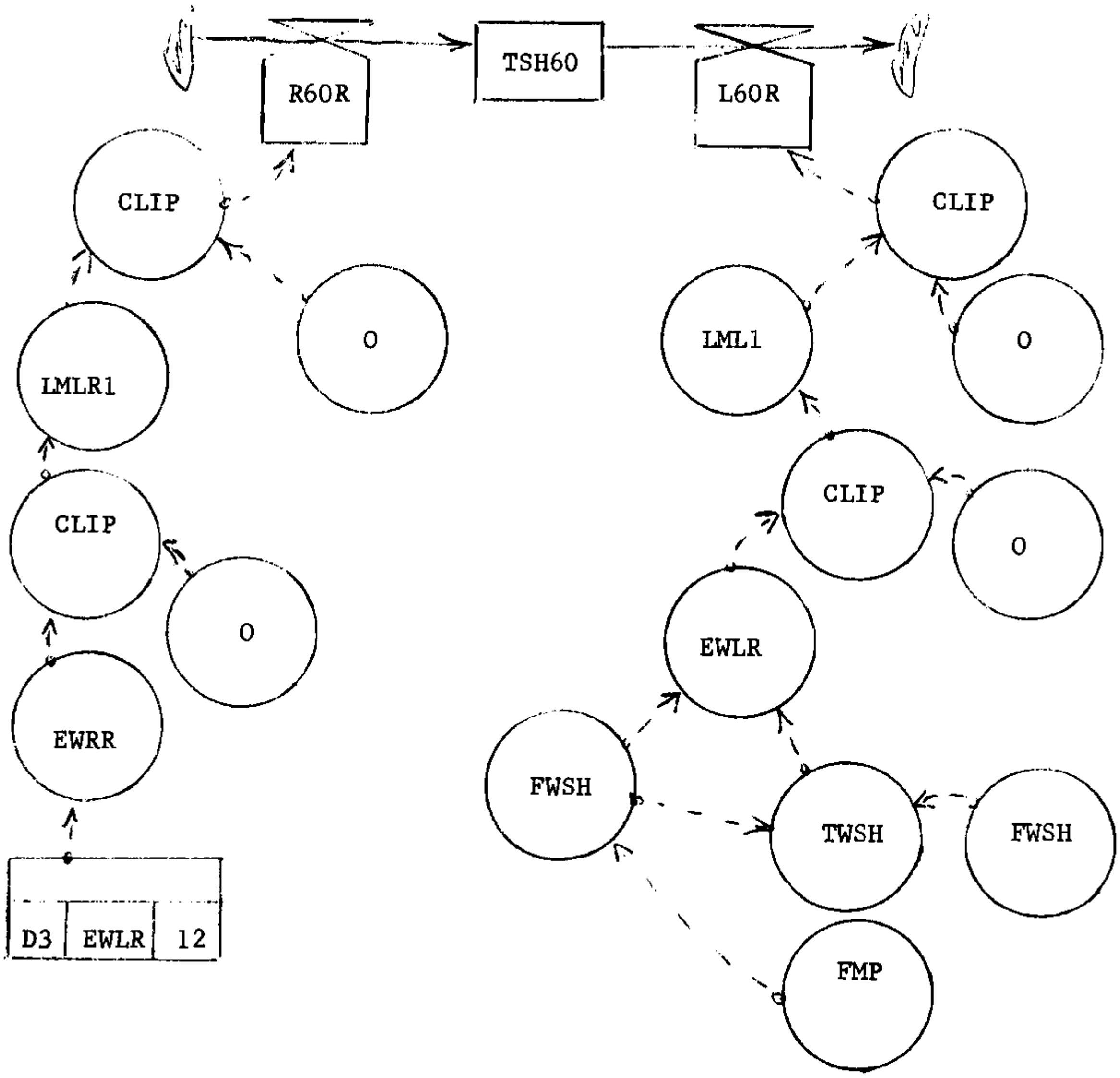


Figure 13. 60 mm Mortar Strength (TSH60)

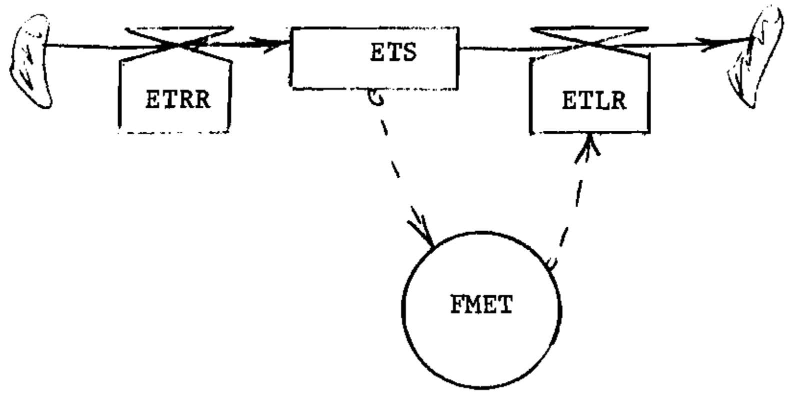


Figure 14. Enemy Troop Strength

To consider the entire system we would have to consider the replacement rate ETRR, but the effectiveness of mixes of weapons can be compared without considering the replacement rate if both are zero; so, for simplicity, let ETRR = 0. Now, the enemy troop loss rate (ETLR) obviously depends on the number of friendly missions delivered (FMD), and on the exposure of the enemy troops (EE), but there is more which must be considered. Some missions are more effective than others and this effectiveness is a function of the number of weapons involved in firing the mission, the effective bursting radius of the rounds fired, the accuracy of the weapons, and the rapidity with which the mission is delivered. Certainly a mission fired with four weapons should be more effective than a mission fired with only two weapons of the same kind, and a round which covers a larger area has a larger chance of destroying a target. Also, a mission which requires a long period of adjustment gives the enemy more time to seek cover and hence reduces the mission effectiveness. There is also a large element of chance involved in each mission because one side frequently must guess at the location of the other side and because no weapon is perfectly accurate. So let us define the troop loss rate (ETLR) to equal FMET/DT, where FMET is friendly mission effectiveness against troops. Now we can define FMET to be the product of all the factors bearing on the troop loss rate.

$$FMET = (CFMD)(FMP)(PETK)(EE)(ETD)$$

CFMD is the current friendly missions delivered, FMP is the friendly mission potential, the sum of the mission potentials for each weapon unit, and PETK is the probability of a troop kill given that the intended target is hit, EE is the enemy exposure factor and depends on the role of the enemy force (attack, defend, or delay) and the friendly mission adjustment delay. ETD.K is the enemy target density and reflects the number of enemy troops in the target area. The DYNAMO equations for this subsystem are shown in Appendix E.

The Decision Functions

We have now discussed all of the subsystems in the system. The previous subsystem, enemy troop strength, contains the variables which we wish to compare and the other subsystems control them through decision functions which bring the other subsystems to bear on the troop strength subsystem.

Mission Potential

This factor brings the type weapon firing each mission, the number of weapons firing each mission, and the size of the area covered by each burst to bear in FMET. This is accomplished by summing the current potential for each weapon type:

$$FMP = FMP60 + FMP81 + FMP42 + FMPH$$

The mission potential development is identical for each weapon type so only FMP60 will be traced. The reader is reminded, however, that the same data is developed, not only for each friendly weapon type, but also by a mirror image procedure on the enemy side of the model, Figure 15.

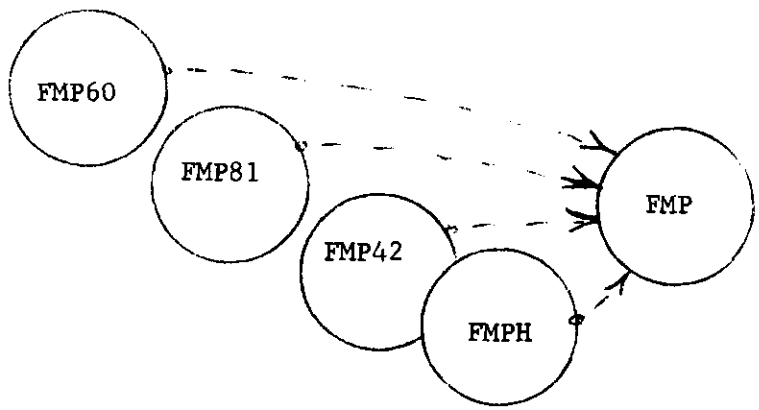


Figure 15. Friendly Mission Potential

$$FMP60 = (EBD60)(WSH60)(OL60)$$

Where EBD60 is the effective bursting diameter, WSH60 is the number of 60 mm mortars in action, and OL60 is an overlap factor to account for rounds from different weapons falling on the same area. WSH60 brings control information to FMP as explained in the following paragraphs.

In the Friendly Weapons Subsystem, the number of surviving weapons (TSH60) in the unit was developed. The Friendly Mission Potential Section modified this information through a series of controlling variables. If the 60 mm unit is active according to the FUA subsystem, then a new variable, USH60, equals TSH60, otherwise USH60 equals zero. If the unit is not displacing then another new variable (MSH60) equals USH60, but if the unit is displacing, the MSH60 equals USH60/2. This is because indirect fire units displace in sections to maintain fire coverage. The ammunition subsection exerts control in the same manner. A third new variable (ASH60) equals MSH60 if there are any rounds on hand, otherwise ASH60 equals zero. Finally, range is considered. If the assigned target is within range, WSH60, the variable in the equation for FMP60, equals ASH60, but if the target is beyond range, WSH60 equals zero. Figure 16 gives a diagram for the mission potential section and the DYNAMO equations for this section are shown in Appendix F.

Mission Effectiveness

The mission effectiveness variable (FMET) is the auxiliary which brings all controlling decisions and functions together to affect the troop loss rate (ETLR). Mission effectiveness is the product of mission potential (FMP) and missions delivered (FMP), which we have already discussed, and three new factors which reflect the internal dynamics of the target. These last three factors are troop density (ETD), troop exposure (FE), and the probability of target kill (PETK) (see Figure 17).

$$FMET = (FMP)(ETD)(FE)(PETK)$$

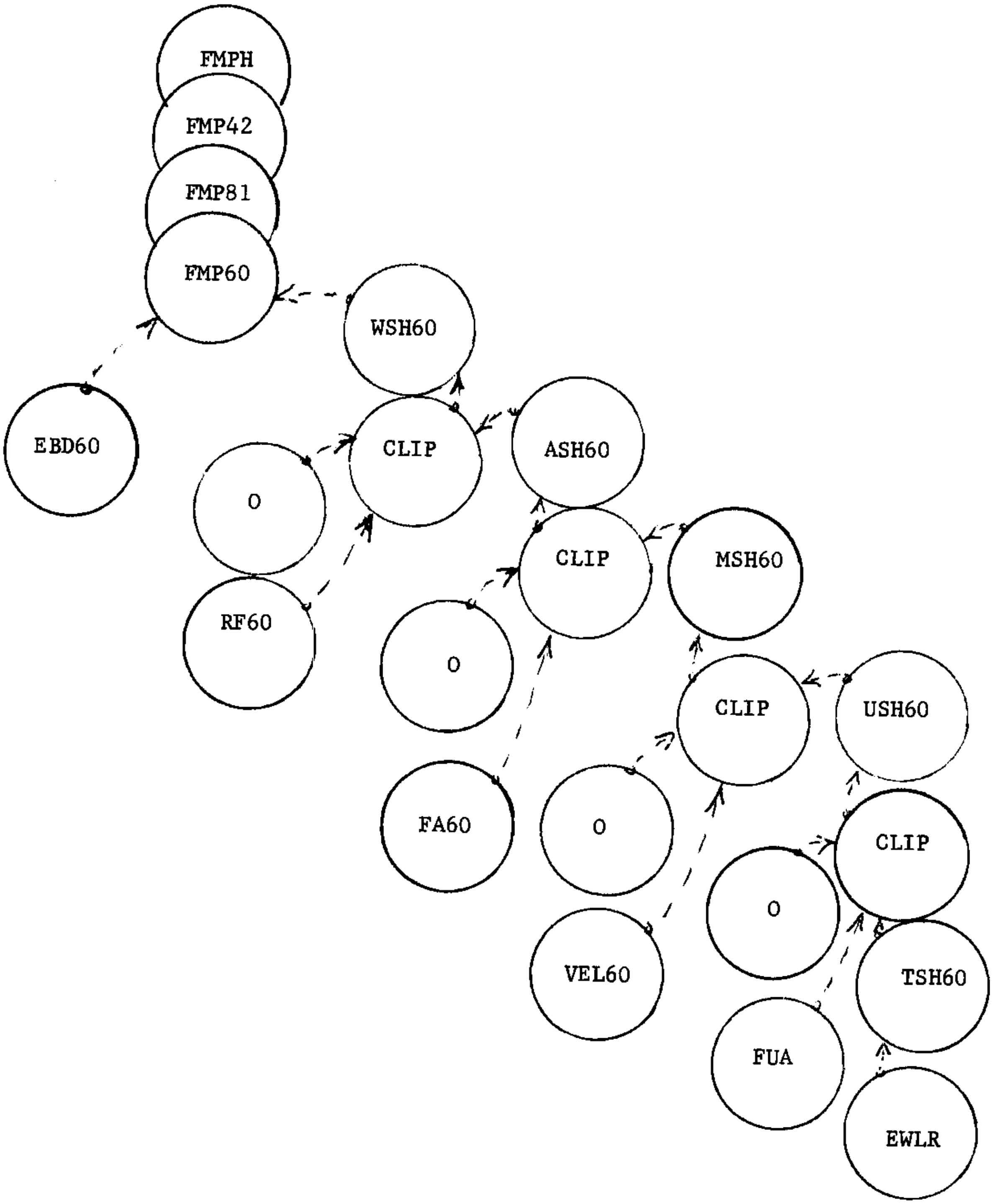


Figure 16. Mission Potential Section

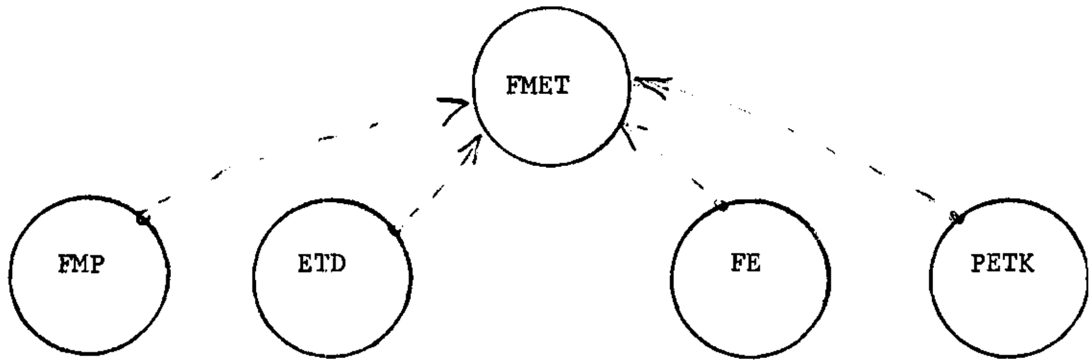


Figure 17. The Mission Effectiveness Variable

We have been talking rather loosely about targets and target areas. To proceed further, we must be quite specific. Since we are taking the point of view of the rifle company commander, let us take the platoon as our basic target. We can then talk about the probability of hitting the platoon target and inside this platoon target we can describe the density of troops and talk about kill probabilities in those terms. This is based on a fairly realistic assumption that companies will always have frontages of a given size and platoons of another lesser size, disregarding actual troop strength. This assumption cannot be fully supported to extremes, but it should be clear that military tacticians maneuver platoons, companies, and battalions and assume, unless forced by dire necessity to do otherwise, that these units are at full strength.

Troop Density. The density of troops in the target area is a function of the enemy troop strength. If we assume, as mentioned previously, that the frontage of each platoon will remain constant and that troops are arrayed linearly, then current troop density is simply the ratio of current troop strength to the length of the troop line. The troop line will change, of course, as the role of the target force is changed. It is necessary to consider target density because this is a dynamic variable in the system which will limit the effectiveness of the enemy effort as time passes. Early target kills will lead to a reduced rate of target kill in the future as long as replacements are not received.

Exposure. A military unit in the field does what it can to minimize exposure to enemy fire. In the defense, elaborate measures are taken if a position is occupied for a sufficient amount of time. In the offense, exposure is reduced by choice of routes, movement at night, when possible, and the use of suppressive fires when other efforts are not sufficient. For all of the efforts made to reduce exposure, there still remain tasks which cannot be accomplished without exposure. The attacking force must close with the defender's position. The defender must patrol, repair, communicate, resupply, etc. The delaying force must withdraw in addition to all the things the defending force must do. Because tasks which must be accomplished require exposure and some of those tasks can be deferred when an attack is under way, the degree of exposure of the target force is dynamic. When a sufficient amount of time has passed without an attack, the need for resupply, communications, etc. compels part of the force to be exposed, but an incoming round will send all exposed personnel to whatever protection is available. The degree of exposure is dependent on the amount of warning time, which we can equate to adjustment time. Given the platoon size target area we have defined and a typical standing operating procedure (SOP), which specifies the percentage of the force to be exposed at a given time, we can rather accurately describe the relationship of exposure to adjustment time.

For a defending force let us assume a typical SOP allowing 50 percent of the force to perform exposed tasks at a time. Then, at the instant of a first round impact near the target, we can expect 50 percent of the target force to be exposed. For a short period that level of exposure will decrease until all exposed troops have reached cover, at which time the degree of exposure will become steady at the minimum exposure the prepared positions offer. After a sufficient period of time with no rounds falling, the need for task accomplishment will force personnel out to exposed locations again. For a delaying target force, much the same procedure is followed except that, when the attacker closes to a prescribed distance, the delaying force must withdraw, causing a period of high exposure. For an attacking force, the level of exposure remains high except that the attacking force can increase its speed and thereby become more difficult to hit. The minimum exposure varies with role. Attacking troops are inevitably exposed to a high degree, while defending troops can have a very low level of exposure if sufficient time has passed to build elaborate fortifications. So we must let EE equal an attack exposure value (EEA), a defending exposure value (EED), or a delaying exposure value (EDL). EE equals a maximum exposure as long as missions are directed away from the target area (i.e., counterbattery fire). When fire starts falling on the troop target, exposure is assumed to react as shown in Figures 18, 19, and 20.

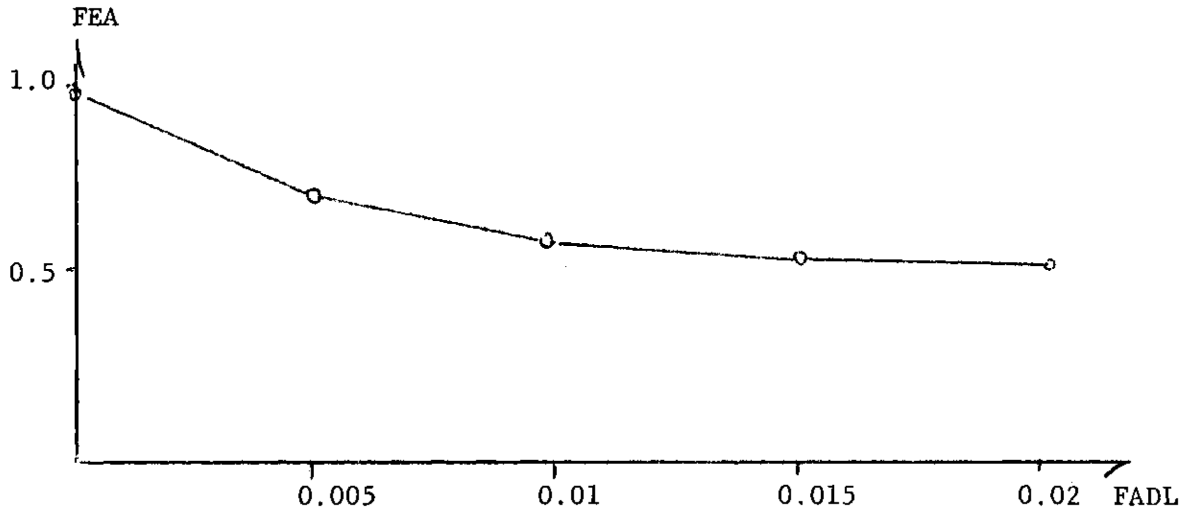


Figure 18. Attack Exposure as a Function of Adjustment Time

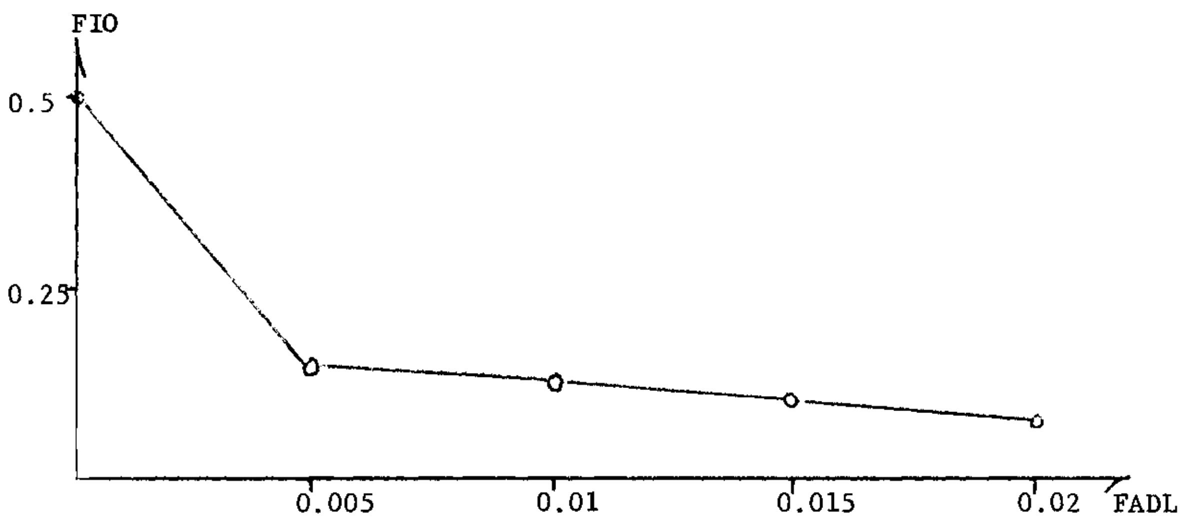


Figure 19. Defense Exposure as a Function of Adjustment Time

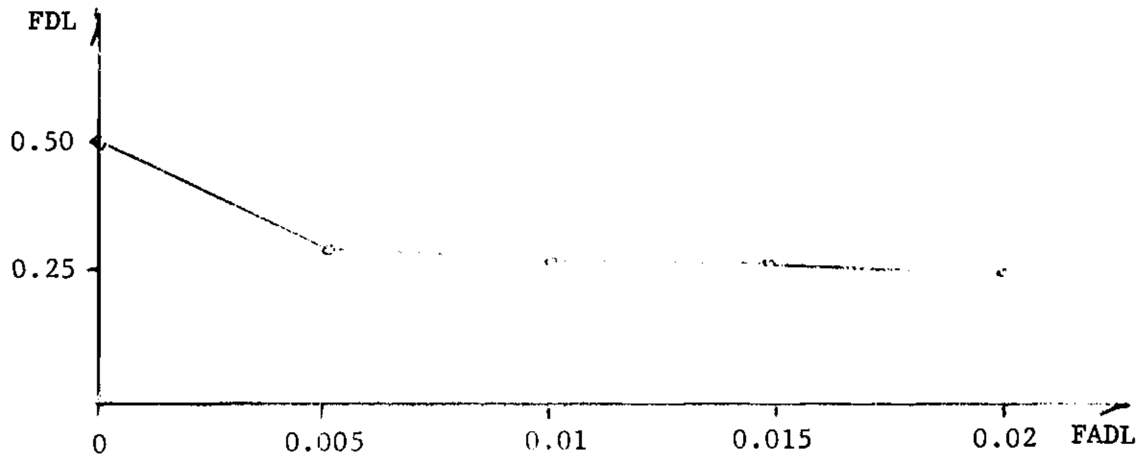


Figure 20. Delay Exposure as a Function of Adjustment Time

In the case of exposure of a delaying target force, only hasty defensive positions will be prepared, hence the higher minimum exposure levels. Because of the added hazard due to hasty positions, the delaying force will stay closer to what protection it has, thus a quicker drop to minimum exposure. MRA is the current range between opposing forces and is generated by the movement section. When MRA is less than 1000 meters, the delaying force withdraws. The mirror image of this section is FE, friendly troop exposure, and is developed identically.

<u>Probability of Troop Kill</u>. PETK attempts to consider the stochastic variables involved in bringing indirect fire to bear. In Chapter III we discussed an extension of Bonder's probability of a target kill and three random variables affecting the kill probability for indirect fire systems, the probability of target hit (or more precisely $P(N \leq X)$), the probability that the target area is occupied, and the probability of a

target kill given the first two. Since the number of rounds in adjustment to hit the target affects the system through the time delay it generates, $P(N \leq X)$ determined the value of FN, the number of adjustments in the section on fire missions. Dynamic input to the probability of target area occupation would be in the form of reaction to an incoming fire mission. We will consider the "fine" reactions of reducing exposure later, but the "gross" reaction of moving away from the impact area is beyond the resolution level of this simulation, hence an assumption of independence for PTAO, the probability of target area occupation, is not inappropriate. We can define PETK to be

$$PETK = (PTAO)(PTEK)$$

where PTAO is the probability of target area occupation and PTEK is the probability of a kill on an occupied target (Figure 21).

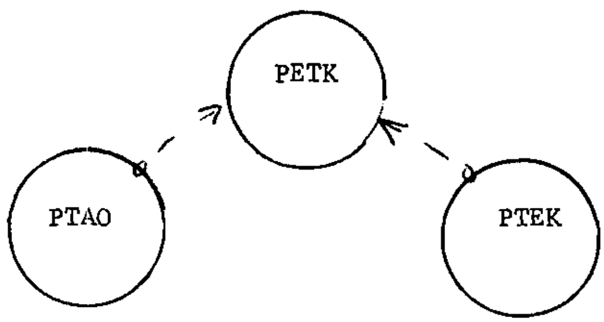


Figure 21. Probability of Target Kill

There is no data available on how many missions are fired on unoccupied targets for the obvious reason that it is frequently impossible to visit a target area soon after a mission is fired, but some useful assumptions can be made based on the author's military training and experience. Let us define the situations in which missions are fired and then estimate the frequency with which these situations occur and the probability of target area occupation for each situation. The situations which we want to define are best described as levels of control. Let us start with observed fire, in which a forward observer maintains visual contact with not only the target area but also the enemy force throughout the mission. The opposite of this is unobserved fire in which the target area may be observed but no visual contact with enemy force exists. In the middle of these two let us define planned fire in which visual contact may not be gained with either the target site or the enemy force, but previous contact has allowed registration and there is good reason to expect the enemy will occupy or pass through the target. Let SO represent the probability of target area occupation under observed fire, SP the same probability under planned fire, and SU the probability under unobserved fire. Now let us assume that most missions are fired on observed targets and on planned targets next and estimate the following frequency of target type occurrence.

Table 2. Assumed Distribution of Missions by Observation Type

SO	.55
SP	.25
SU	.20

For the observed target we must say that PTAO equals 1.0 because we could not call it an observed target by our definition if it were not occupied. So, SO equals one. For the planned target, a difference seems logical depending on the role of the target force. If the target force is attacking, then it seems likely that the force will move through the target site, but for a defending target the planner cannot expect the target to move into the target site. An estimate of PTAO = 0.9 if the target force is attacking and 0.7 otherwise seems appropriate. For the unobserved target it again seems logical to expect a difference between an attacking force and a defending force, but the probability should be considerably lower, say 0.5, if the target is attacking and 0.4 if the target is defending, see Figure 22 for a diagram of this probability.

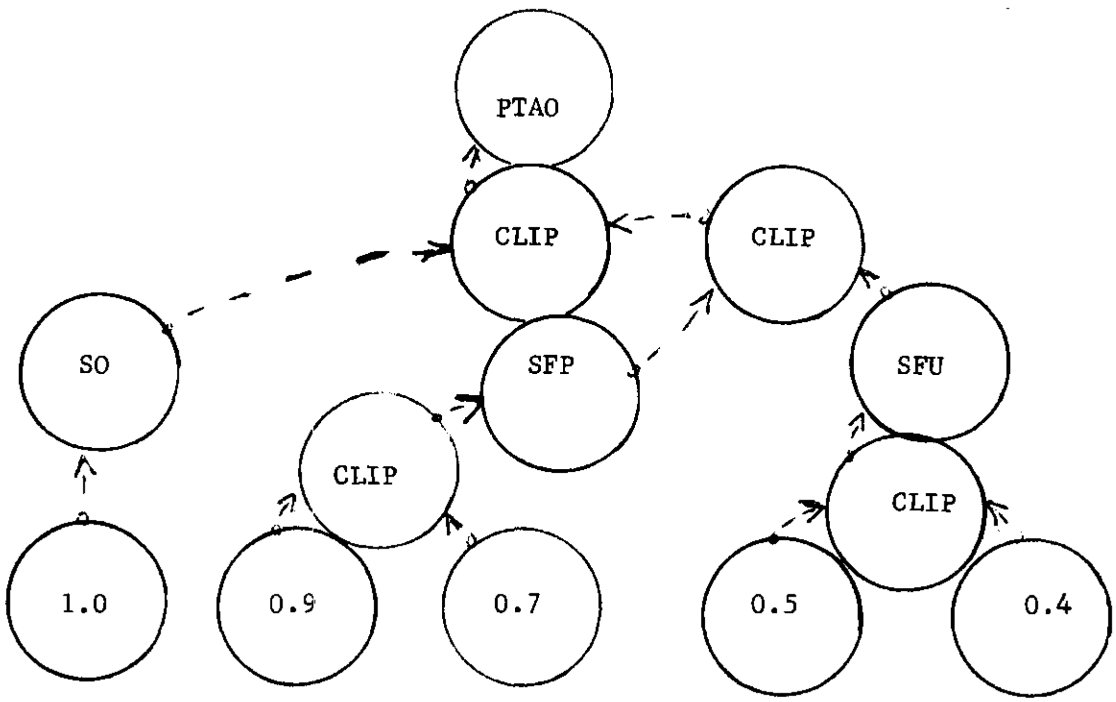


Figure 22. Probability of Target Area Occupation

PTEK is basically the ratio of the actual length of the troop line which a given burst intercepts to the maximum length it might intercept. Whether the role of the target force is attack, delay, or defend, the troops will be arrayed in a generally linear configuration. In the assault, troops are formed in a line to give maximum fire power to the front (Figure 23).

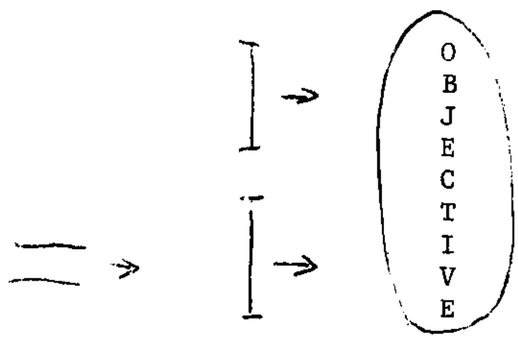


Figure 23. Typical Company Assault (Two Platoons Leading)

The above figure shows a company assault with two platoons committed, one in reserve. Note the linear arrangement of all three platoons. In the delay or defense, troop positions are also arranged linearly within the target area. Figure 24 uses the standard symbols for platoons in a defensive position. The actual troop positions are on the forward edge of the symbols with only the command group back within the symbol.

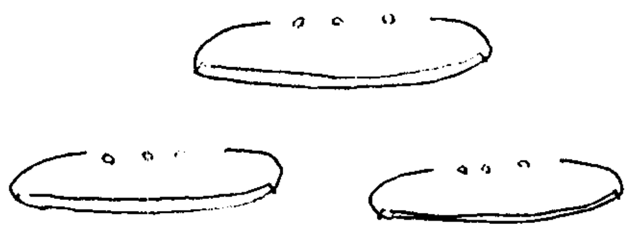


Figure 24. Typical Company Defense

By simplifying to say that all troops are arranged linearly regardless of role, we can easily approximate the length of the troop line which is intercepted by the bursting round. Each high explosive round has an effective bursting diameter, EBD, which is the diameter of a circle along the perimeter of which 90 percent of the targets exposed will be hit. If we assume that all targets exposed inside will be hit and none outside, then we can use the circle described by the appropriate EBD and an impact point to determine the length of the troop line which has been intercepted, Figure 25.

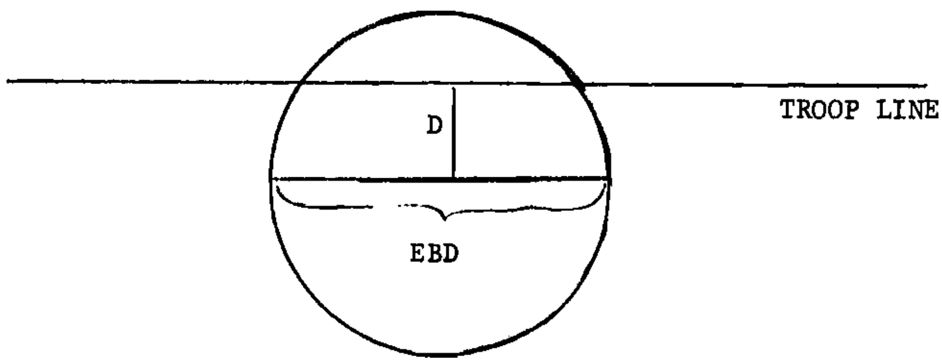


Figure 25. Length of Troop Line Intercepted by Burst

If D is the shortest distance between the point of impact and the troop line then by trinonometry:

$$TL/2 = (EBD)/2) \quad COS \quad (2PI)(D/EBD/2)$$

or simplifying:

$$TL = EBD \; COS \; (2PI)(2D/EBD)$$

PTEK then equals the ratio of TL to EBD as long as the cosine function is in the first quadrant (that is, D is less than EBD/2). When D is greater than EBD/2, PTEK must equal zero. It remains to determine a value for EBD and D. Since the mix of rounds falling on the target will vary from one time interval to another, no single EBD can be used. The most appropriate value seems to be the average for all weapons firing. This gives us the results to be expected from a system of identical weapons with identical EBD firing in sheath. Proper control of the real system will give the sheath effect we assume, so no great loss in accuracy should be caused by these approximations. (Diagrams are given in Figures 26 and 27.)

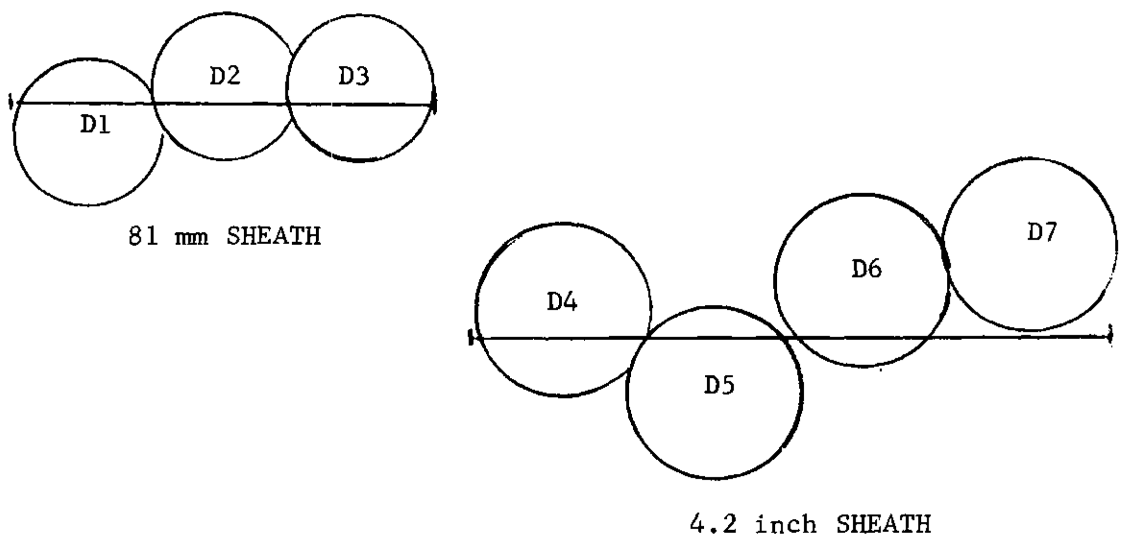


Figure 26. Hypothetical Real Impact Behavior

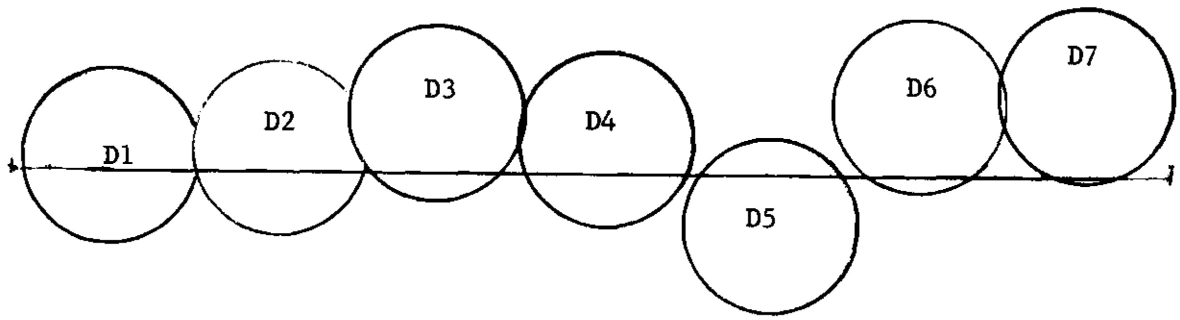


Figure 27. Model Approximation of Impact Behavior

The approximation would be unsuitable, however, if the total sheath length were ever to exceed the length of the target line. In this problem, the sum of the frontages of the target platoons is never exceeded by the potential sum of the effective bursting diameter. For the attack, a platoon frontage is expected to be about 200 meters. Three platoons give a total troop line length of 600 meters. For the defense platoon, frontage is expected to be about 400 meters, giving a total troop line length of 1200 meters. Platoon frontage in the delaying role is even greater than that for the defense. If we take the number of weapons in our present system and replace each weapon with the 4.2 inch mortar (which has the largest effective bursting diameter of 40 meters), then we get 14 times 40 meters or 560 meters total, which is less than the total platoon frontage at its least. Thus, we can take the average effective bursting diameter for the missions being delivered and disregard the possibility of exceeding the length of our hypothetical troop line. Let the current average effective bursting diameter for friendly fires by FEBD. Then

$$\text{FEBD} = (1/\text{FBFA})(\text{FMP})$$

where FBFA is the number of weapons currently firing. The displacement of the burst from the troop line, D, we will call FD. This is because it is a function of the accuracy of the weapon system and we must differentiate between friendly and enemy systems which are operating concurrently. FD is a random variable dependent on the accuracy of the weapons system. This variable is universally accepted as normally distributed with a mean of zero and a standard deviation of CEP (circular error probable) which is published for each weapon type. Since we may have several weapons firing, we must again average the current displacement and CEP. Let FCEP be the average circular error probable, then

$$\text{FCEP.K} = (1/\text{FBFA})(\text{FCP60} + \text{FCP81} + \text{FCP42} + \text{FCPH})$$

where

$$\text{FCP60} = (\text{CEP60})(\text{WSH60})$$

A diagram of the probability of target kill is given in Figure 28 and the DYNAMO equations for this section are shown in Appendix G.

Significant Differences Between the Friendly and the Enemy Models

As discussed previously, the friendly and the enemy models in this simulation are structurally identical. Differences exist because of two factors: enemy equipment and common tactical procedures.

While the friendly force in our model is equipped with the weapons the Infantry Board wishes to consider, the enemy force must be equipped with weapons which our tested weapons might be expected to face. It is not unlikely at all that the friendly weapons we are testing might be fired

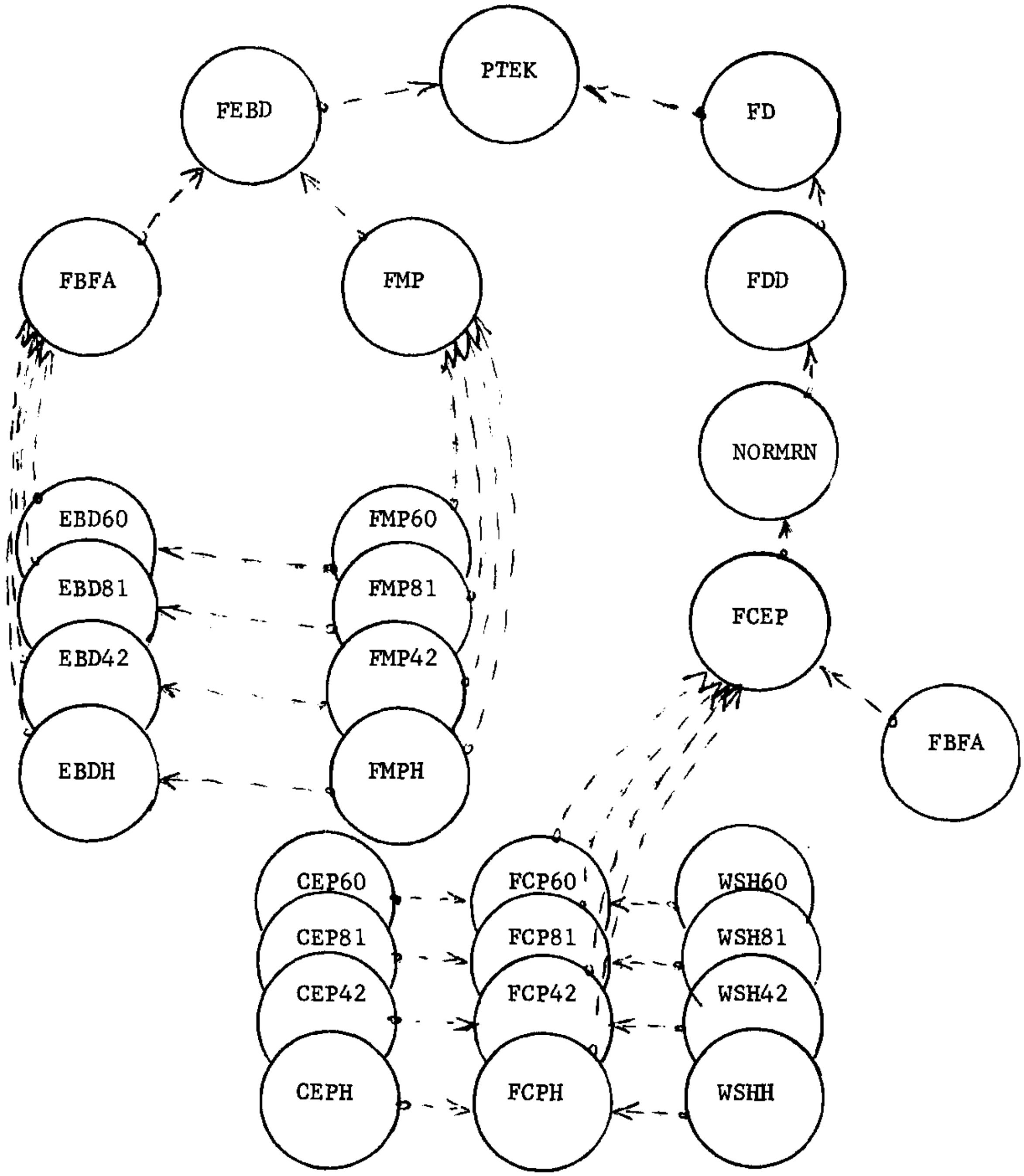


Figure 28. Probability of Target Kill Section

upon by any enemy weapon, but, if enemy weapons which normally fire from sites beyond the range of our friendly weapons were included, then it would be necessary to consider friendly weapons of sufficient range to counter them. Unless we assume (not too unreasonably) that the effects of weapons of greater range than those being considered will balance each other, then we must ultimately include every weapon in the opposing arsenals. This assumption is made here, and the only weapons included in the enemy force are the light mortar, the heavy mortar, and the gun howitzer.

These are not real weapons. The selection of real enemy weapons would involve strategic considerations far beyond the purpose of this study and would reduce usefulness by being too specific. Because this country does have several different potential opponents, a subjective approximation has been made. The U. S. Army has approached the problem of multiple potential opponents by creating a fictitious opponent for training purposes. This opponent, known as the Aggressor Army, is a composite of the most significant features of the several potential opponents and is kept up to date to insure that tactics and techniques developed in training are realistic (23). The weapons employed by the enemy force of our study are those of the hypothetical Aggressor Army which are employed at company, battalion, and regimental levels. In the enemy force, then, there are only three different types of weapons and they are deployed and controlled as follows. The light mortar is deployed and controlled at battalion level with six weapons in the firing battery. The heavy mortar is deployed and controlled at regimental level with six weapons in the battery. The gun-howitzers are deployed at regimental level and controlled at division level with six weapons in the battery.

The other difference between the two subsystems is that, while the friendly force remains constant in terms of organization at company level, the enemy force changes with role. It is a well known tactical rule of thumb that an attacking force should have three times the strength and firepower of its defending opponent. This is to insure success while overcoming the disadvantage of exposure we discussed earlier. In order to keep the friendly force constant, the enemy force is varied. If the friendly force is attacking, then the enemy strength and number of weapons is that of a platoon, because presumably a company would not be called upon to attack a larger force. On the other hand, if the friendly company is defending, then the enemy force has the strength and weapons distribution of a battalion, because a company should expect to be attacked by a battalion under the three-to-one rule of thumb.

Movement and Terrain

This section takes input data which specify tactical roles, terrain characteristics, and initial locations for each target and firing site and generates locations, rates of movement, and ranges for each target or firing site.

Tactical Decision Rules

The movement of the friendly troop position (the rifle company) will be represented by the movement of the center of mass of the unit. There are doctrinal rules for movement here which are relatively easy to simulate as long as the rules are obeyed by the real unit. We will assume that these rules will be obeyed.

The friendly unit will either advance or withdraw. We will make this decision exogenously by assigning a value to a switch variable SREF:

SREF = 1 implies forward motion for the friendly unit

SREF = -1 implies withdrawal for the friendly unit.

If the friendly unit is advancing, then the situation will dictate the rate of advance and the tactical state of the advance. An advance can be either an attack or an exploitation. An attack is a deliberate and cautious advance in strength to seize occupied positions. In this case, the rate of movement for a rifle company will be approximately a slow walk or about 1000 meters per hour. An exploitation is a bold tactic for use against a weakened enemy, intended to encircle and destroy him. The rate of advance here usually depends on the availability of vehicles, since it is also usually a movement of long distance. The average rate of movement here will be about the rate at which a vehicle can proceed overland (that is, off the road) or about 5000 meters per hour. The friendly unit may also not attack, of course, in which case the rate is zero. This decision also will be made exogenously through another set of switch variables.

SR = 0 implies exploitation (average 5000 meters per hour)

SR = 1 implies decision to be made by SSR

SSR = 1 implies 0 meters per hour

SSR = 0 implies attack (average 1000 meters per hour)

These input variables are applied through decision equations which set ROLE equal to 5000 if SR equals zero and a dummy variable, OROL, if not. OROL then equals 1000 if SSR equals zero, and sets OROL equal to zero if SSR does not equal zero. ROLE is the average rate of movement and OROL is a dummy variable which allows ROLE to have three alternative values.

If the friendly unit is advancing, the above covers the doctrinal rules for the situation. If the friendly unit is withdrawing, however, the rules of motion are more complicated. A unit which is withdrawing is somewhat dependent on the enemy's rate of advance; however, for simplicity, we will let the enemy troop movement be the mirror image of the friendly unit. That is, we will let the average rate of advance for the enemy units be the same as the friendly unit for both the attack and the exploitation. Then we can let the average rates of withdrawal for the friendly unit also be zero, 1000, or 5000 meters per hour, depending on the defensive tactics. We can then pick the defense tactics exogenously by selecting a set of rules. These defensive doctrinal rules are as follows: If a defense is ordered, then the average rate of movement is zero for the defending unit. In application this would presumably be true unless the defense were unsuccessful, in which case some decision on withdrawal would actually be made rather than allowing the unit to be lost. In reality, the reserve would probably be committed to counterattack and restore the position, but we are interested in the fire support element of battle and its effect on a rifle company, so the introduction of reserves, while tactically meaningful, will tell us nothing about the effect of indirect fire on the rifle company in defense. Additionally, if the counterattack we have discussed were to fail, we would still need a decision rule for withdrawal from a defensive position. We will assume the following decision rule: Penetration of a defensive position by twenty or more meters will cause the position to be abandoned.

Of course, the defense is not the only retrograde tactic. The defensive unit may conduct delaying tactics in which it is intended to give up positions. In this case, the defensive unit occupies a position until the attacker comes within small arms range, at which time the defensive unit withdraws to another defendable position. Because we are assuming that the position defense tactic includes a withdrawal decision rule, the difference in this simulation between defense and delay is the withdrawal decision rule and the rate of measurement.

The withdrawal is the mirror, for our purposes of the exploitation. It is movement to the rear as quickly as possible in order to avoid annihilation. Presumably, it is a rapid movement to reach a good defendable position, but at the point where a defendable position is reached, this tactic is dropped and defense or delay is conducted, so we will consider withdrawal to be a movement at maximum speed without delaying actions.

Each delaying action or defense involves the decision to stop and the decision to move back again. We have discussed the decision to begin movement. The decision to stop and occupy a position is based in part on terrain. We will assume that the defending force will occupy the military crest of each succeeding ridge and then approximate that position by defining it to be the contour line on the ridge seven eighths of the way up the rising ground. A diagram of role switches is given in Figure 29.

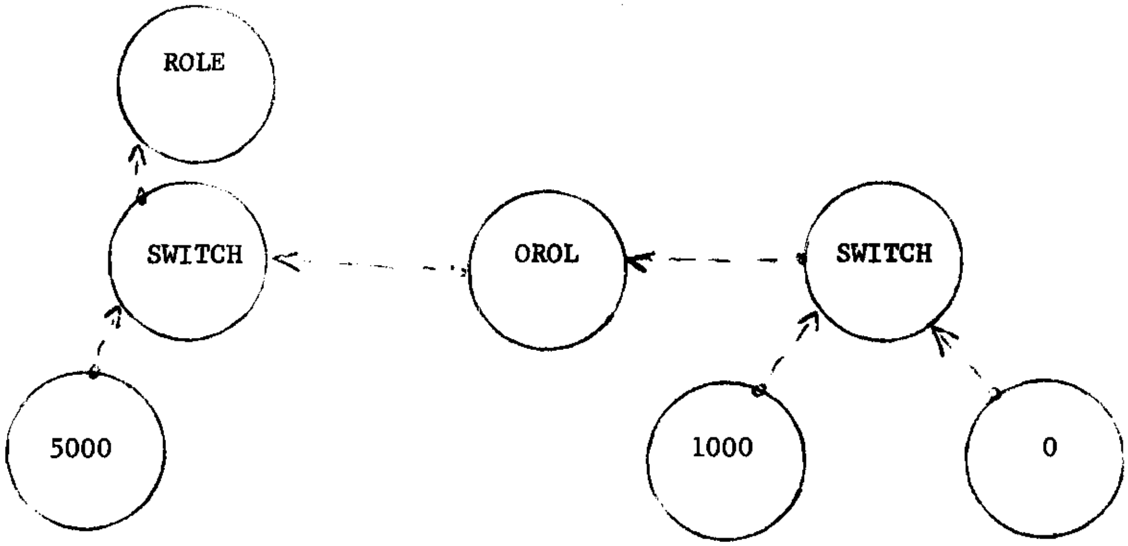


Figure 29. Role Switches

Terrain

The environment invariably has a profound effect in combat actions. If affects the frequency and duration of actions in the daily change from day to night. It may hinder, help, or prevent action as weather factors often do. The single most important environmental element, and the only one considered in the model, is the terrain. The nature of the terrain is, itself, frequently as important an element of a tactical decision as is the nature of the enemy. In many ways, use of terrain may be a dominant consideration, with tactics and man made equipment occupying a supporting role. The commander who must defend or delay will use the terrain to his best advantage, and will use obstacles and troop positions to complement the obstacles created by the terrain. The commander who must attack will find his tactics and equipment choices dictated by terrain. For example, armored forces must be used on flat terrain because infantry forces would be too exposed. Infantry must be used in rough or mountainous terrain because armored equipment becomes road bound and, hence, too exposed. Defensive positions and attack objectives are chosen based, at the tactical level, on terrain considerations, because high ground can be used to dominate lower ground.

More general simulations such as IUA consider terrain to a very high resolution by simulating actual terrain. For example, the terrain model for IUA is built to carefully reproduce the Fulda Gap area of Germany, where the opening battles of World War I, World War II, and the Battle of the Bulge occurred. While this location is historically proven to be strategically important, a terrain model based exclusively on this terrain will not reflect very well the terrain of South Vietnam, or North Africa, or even Austria, which is relatively close at hand.

The terrain model for this simulation, while lacking the resolution of a simulation like IUA, has considerably more flexibility. The IUA model considers terrain to consist of three levels of complexity, the gross features easily identified as hills, ridge lines, and valleys, the irregularities in these features such as gullies, outcroppings, and spurs, and the roughness characteristics such as rocks, vegetation, boulders, buildings, etc. This simulation uses a similar breakdown to consider the elements of terrain important to tactical decisions. It does so with less resolution, however, because, while the IUA model is limited to one place, this model is limited to one type of dominant terrain feature, the ridge and valley complex. The altitude of these ridges and the distance between them may be set at any desired level through input data. The source of this gross topography is a cosine function. Intermediate features are generated by another cosine function of variable period and amplitude and the roughness is generated by a uniformly distributed random number generator of controllable range. This information is generated as elevation and slope date for each target location and firing site. The input terrain variables are as follows: TAVZ is the average elevation. For all test runs, TAVZ was set at 1000. TZ is the gross variation of ridge height. For test runs, TZ was set at 500 so that elevations run from about 500 to 1500 meters. TROL is the average level of roughness and was set for tests at 10 meters. TRND is the range of variation for the roughness characteristic and was set at 10. Due to a characteristic of the DYNAMO equation for uniformly distributed random numbers, this allows a uniform random variation from 0 to plus or minus 5 meters. TPP is the period of the gross cosine wave, or the gross distance between ridge tops. For test runs, TPP was set at 2000 meters. TPPP is the period of the secondary features and was set at 100 meters for tests. The above input variables are combined as follows for all elevation equations:

$$TPZ = TZ + TPZZ$$

where TPZ is the current maximum ridge height;

$$TPZZ + (TZZ) \cos ((2PI)(1)/TPPP)$$

where TPZZ is the current maximum variation in secondary roughness;

$$TZZ = TROL + TRNDO$$

where TZZ is the current roughness variation; and

$$TRNDO = (TRND) \text{ NOISE}$$

where TRNDO is the current value of the random number generator.

Because of another characteristic of DYNAMO, the values of TRNDO will be identical from run to run. Hence, the terrain model will be identical among runs as long as terrain settings are not changed. This set of equations with values indicated generates a terrain profile similar to the sketch shown in Figure 30.

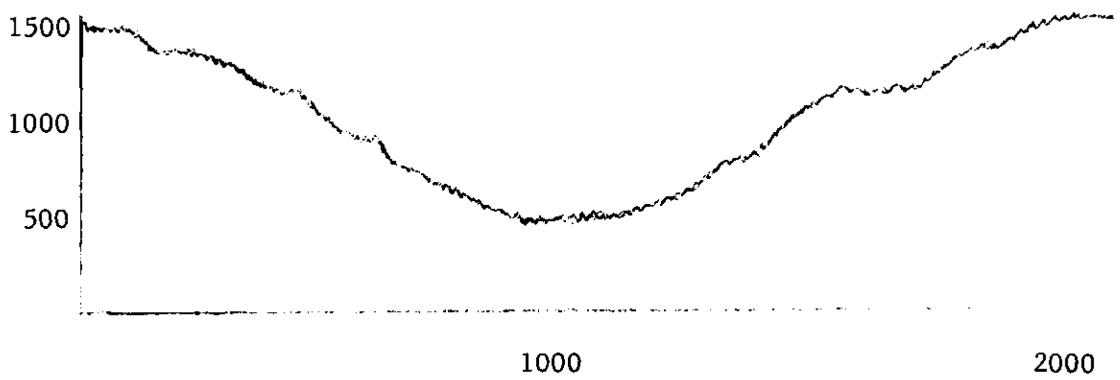


Figure 30. Profile Sketch of Simulated Terrain

TPZ and TPP are used in the computation of current elevation and slope for each target and firing site.

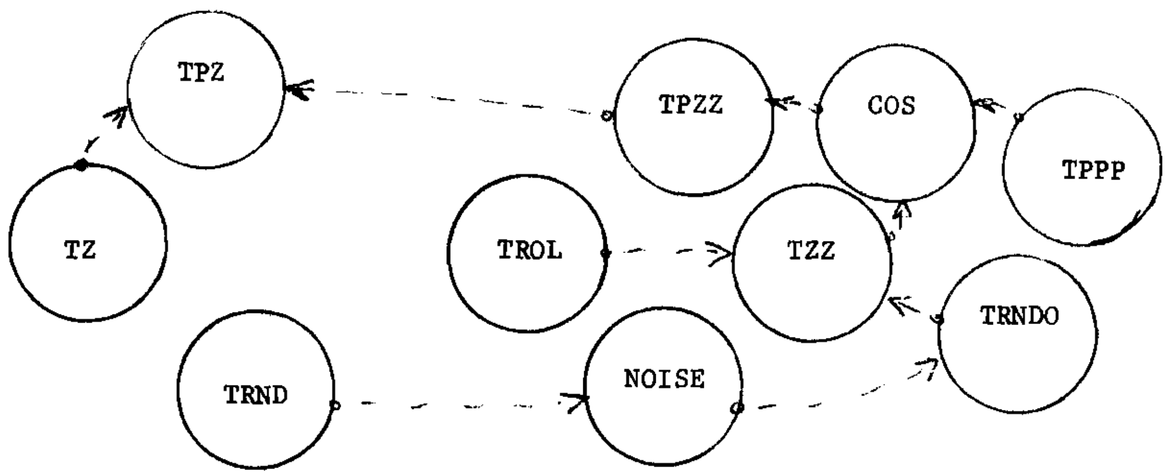


Figure 31. Current Maximum Ridge Height (TPZ)

Troop Target Locations

The friendly and enemy troop location modules are identical in structure. The only difference is the change in sign of SREF, the attack-withdraw role selector. We will develop the enemy troop location, ETG, since all previous discussion has taken the enemy troop location as the troop target.

The initial location is an input and was specified for tests as

$$ETG = X + 10500$$

where X is a common reference point and was set for tests at X = 5000

$$ETG.K = ETG.J + (DT)(ERTU.JK - 0)$$

ERTU is the rate of movement, which may be positive or negative depending on SREF.

$$ERTU = (SREF)(ERTUU)$$

$$ERTUU = CLIP\ (ERTA,\ EFDP,\ 0,\ SREF)$$

ERTA is the current attack movement rate, EFDP is the current retrograde movement rate.

$$ERTA = CLIP\ (ERT1,\ ERTA1,\ MRA,\ 460)$$

MRA is the current distance between troop locations. ERTA equals either ERT1, if MRA is greater than 400 meters, or ERTA1 if MRA is less than 460 meters. Four hundred sixty meters is maximum small arms range. This decision reflects more cautious movement when attacking under small arms fire.

$$ERT1 = ROL1 + (ROL2)(SLETG)$$

ROL1 is the average rate of movement from the role switches.

ROL1 = 1 + ROLE

ROL2 = ROLE/2

ROL2 is the amplitude of the slope controlled portion of the current movement rate.

SLETG = (-1) SIN ((2PI)(ETG/TPP)

SLETG is the current slope of the terrain at ETG. It is the first derivative of ELETG, the current elevation of ETG which will be developed later.

ERTA1 = 1000

This reflects the reduction to attack rate if the initial rate of movement was that assigned to the exploitation. This completes the decision structure among attacking rates.

The reader will recall that the retrograde movement rate is represented by EFDP.

EFDP = CLIP (ERTA, ETMC, MAR, MRA)

If MRA, the actual range, is less than MAR, the minimum acceptable range, then EFDP equals ERTA, or the attack and withdrawal rates are the same. As long as MRA is greater than MAR, then EFDP equals ETMC. ETMC is another decision variable which will cause the defending or delaying force to stop at the military crest of a ridge.

ETMC = CLIP (ETOP, ERTA, ELETG, TMZ)

If ELETG, the current elevation of ETG is greater than TMZ, then ETMC equals ETOP.

$$ELETG = ELEET + TAVE$$

$$ELEET = (TPZ)\ COS\ ((2PI)(ETG/TPP)$$

Otherwise, ETMC equals ERTA the attack rate.

$$TMZ = (TMZZ)(7)/8$$

$$TMZZ = TAVZ + TPZ$$

TMZ is the maximum elevation which might exist but for the cosine function. This puts the defensive position at the military crest of the ridge, but might also select the wrong slope; so another decision variable (ETOP) is used to insure the defensive position is on rising ground with respect to the direction of movement. Figure 32 is a sketch of the military crest approximation and Figure 33 is a diagram of the enemy target movement.

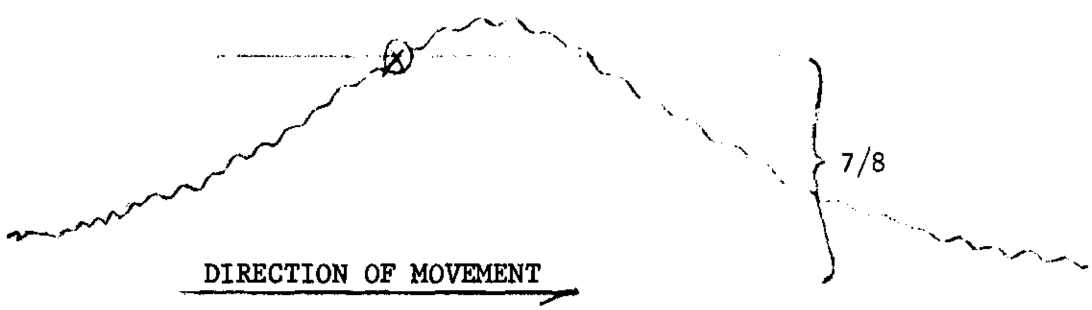


Figure 32. Military Crest Approximation

$$ETOP = CLIP\ (0,\ ERTA,\ ELETG.K,\ ELETG.J)$$

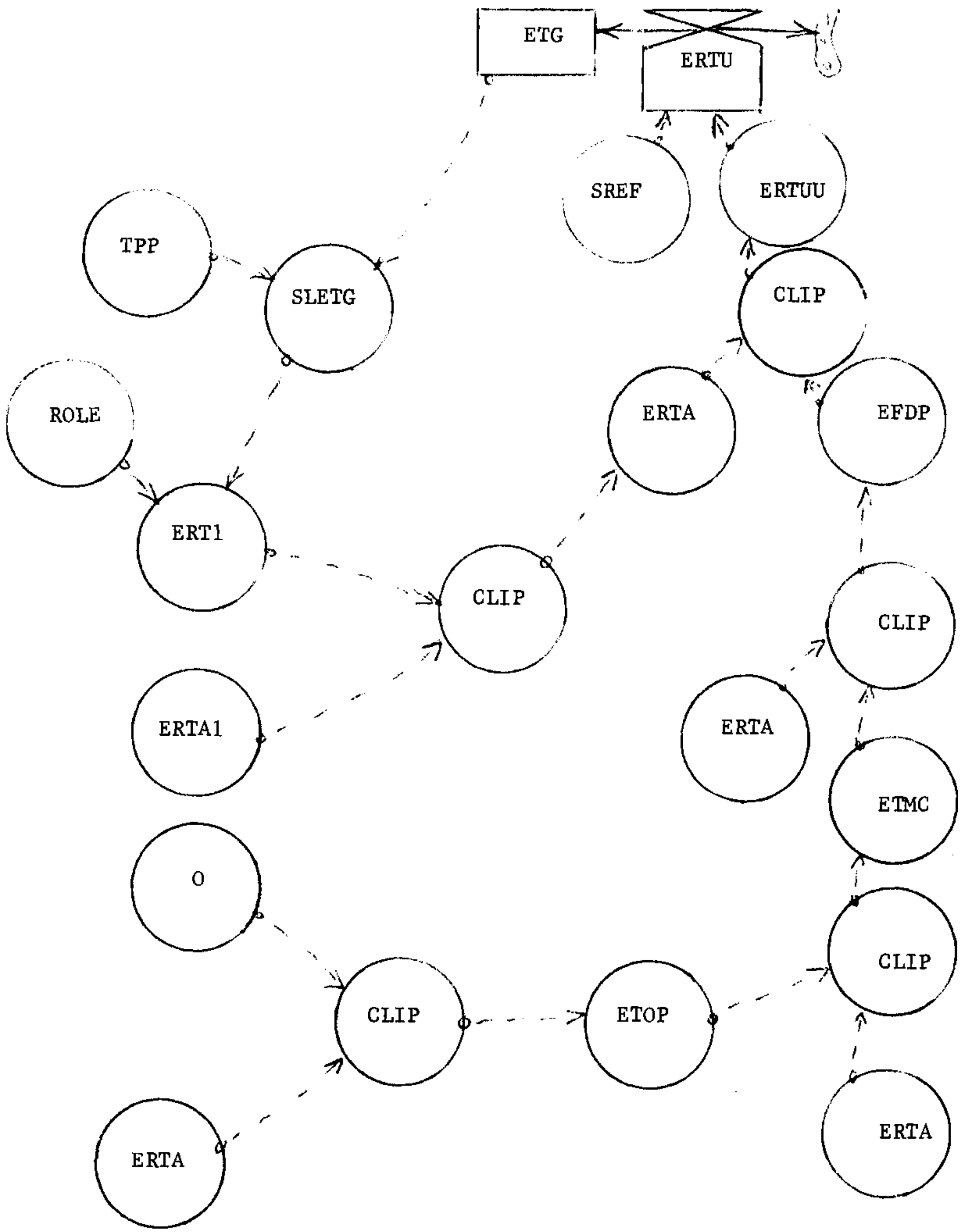


Figure 33. Enemy Target Movement

Weapons Locations

All of the weapons locations are developed identically. We will discuss in detail only the module generating the 60 mm mortar location, X60. The initial location X60 is an input. For tests, X60 = 9400.

$$X60.K = X60.J + (DT)(VEL60.KL - 0)$$

where VEL60 is the movement rate and

$$VEL60 = (SREF)(VEL60)$$

Indirect fire units must displace occasionally either to avoid being overrun if their role is defensive or to stay within range if the role is offensive. Because it is desired that every unit be capable of firing at all times, the decision to move is made early enough that the unit can move in two echelons and keep half of the firing battery operational throughout the displacement period. This was discussed to some degree in the development of FMP, the friendly mission potential. The simulation equations approximate the logic involved in the displacement decision. The approximation is this: If the enemy role is attack, then displacement is begun when actual range to the friendly troops target is greater than or equal to three quarters of the maximum effective range for the light mortar. If the role is defense or delay, then displacement is begun when actual range to the friendly troops target is greater than or equal to three quarters of the maximum effective range for the light mortar. If the role is defense or delay, then displacement is begun when the actual range is less than one quarter of the maximum effective range.

To halt the displacement, the approximating decision rule is: In each case displace five twelfths of the maximum effective range. This puts the new firing site initially at a location where two thirds of the maximum effective range is available for use (see Figure 34 below).

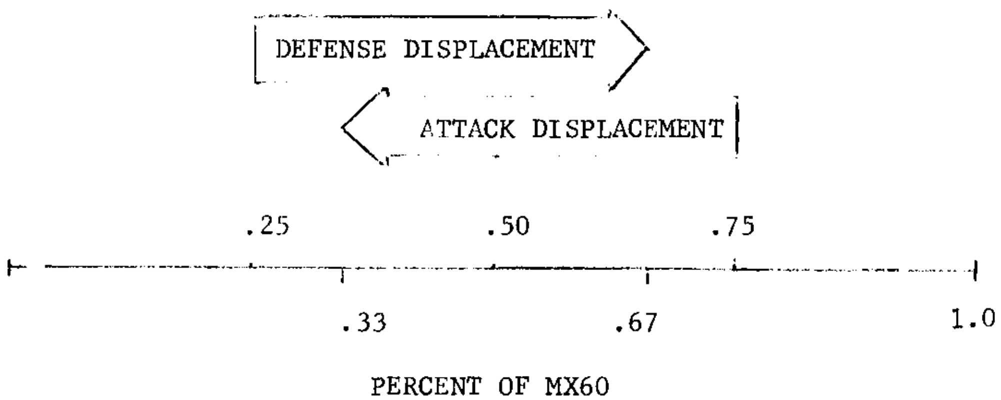


Figure 34. Firing Site Displacement as a Function of Maximum Effective Range

The input to this series of decisions is a dummy variable, V60.

$$V60 = AV602 + (AV604)(SLX60)$$

AV602 is one half the average displacement rate and AV60 is one fourth the average displacement rate. This halving is done to reflect the fact that two complete moves are made in each displacement and the displacement time period is approximately twice the time to move once to the new site.

$$AV602 = AV60/2$$

$$AV604 = AV60/4$$

SLX60 is the current slope at X60

$$SLX60 = (-1)\ SIN\ ((2PI)(X60/TPP)$$

and AV60 is an input. For test runs, AV60 was set to equal ROLE, because the 60 mm mortar would normally be carried right with the troops.

Other weapons location modules vary from this in the average movement rate. For example, the enemy heavy mortar might be vehicle transported so that AVHM would be set equal to 15000, or about 10 miles per hour (see Figure 35 below).

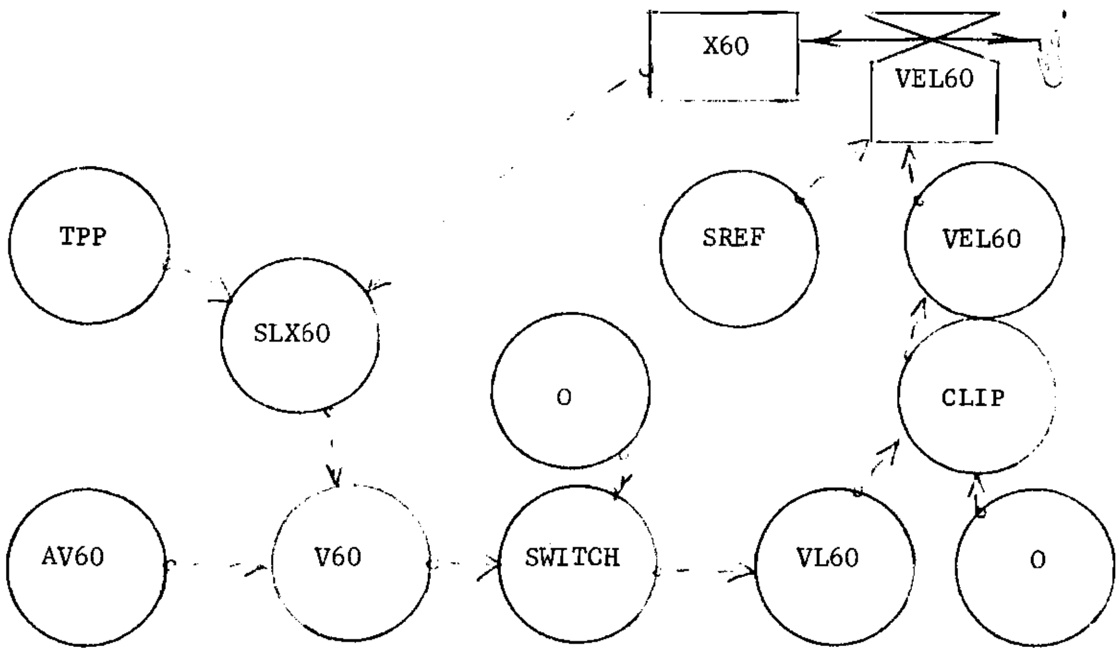


Figure 35. 60 mm Mortar Location

Ranges for each weapon are computed as the following example for the 60 mm mortars.

$$R60 = X60 - EETG$$

where X60 is the current 60 mm mortar location and EETG is a current general target which may be any of the friendly targets.

$$FFTG = CLIP\ (FCTG,\ FTG,\ RANDO,\ 800)$$

FCTG is a general counterbattery target if RANDO is greater than 800. Otherwise, FFTG equals FTG, the friendly troop target. This decision rule is identical to the mission switch rule in the Enemy Mission Effectiveness section, and the mirror image of the rules in the Friendly Mission Effectiveness section which we discussed earlier. FCTG equals X60 if the current rounds fired for the 60 mm mortar is greater than that fired by the other enemy weapons units, and likewise equals X81, X42, or XH if that battery currently fired the most rounds.

The reader may observe in the Appendices that the logic and decision variables are identical to those involved in selecting the specific weapons strength loss rate to which FSLR, the general friendly weapons loss rate, is applied. DYNAMO equations for this section are shown in Appendix H.

CHAPTER VI

MODEL ANALYSIS

Validation

Figures 36 and 37 show replications of the current standard mix superimposed. Each replication draws from a new and different table of random numbers, otherwise variables are identical. A smoothed mean curve is shown on top of the replication and comparison with the predicted model behavior of Figure 6 implies a valid program. Computer plotted output is shown in Appendix I.

Test Mixes

While the ultimate goal of the Infantry Board is to select a best weapons mix, this study will only test selected hypothetical mixes to evaluate the ability of the simulation to discriminate among mixes. In order to select meaningful test mixes, we must consider some of the likely constraints which the Infantry Board will probably face.

First, it is most likely that the present cost levels will remain unchanged; therefore, no alternative mix may exceed the cost of the current mix.

Secondly, it is likely that only minimal changes in total personnel strength will be allowed; therefore, let us assume no alternative mix may exceed the present total number of indirect fire support personnel.

Third, the primary organization of the battalion will not be changed. The cost constraint is highly complex and might well require another study

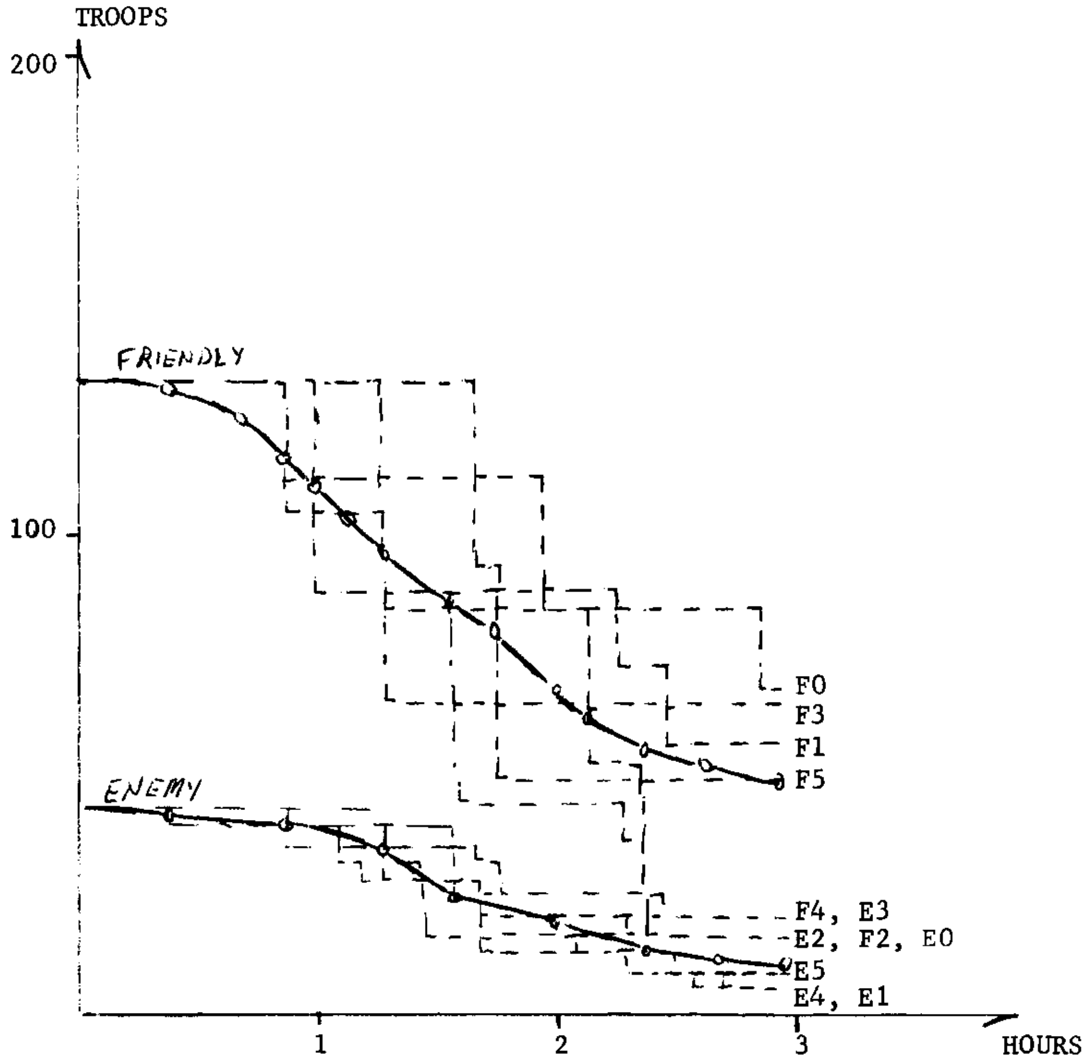


Figure 36. Validation Runs (Attack)

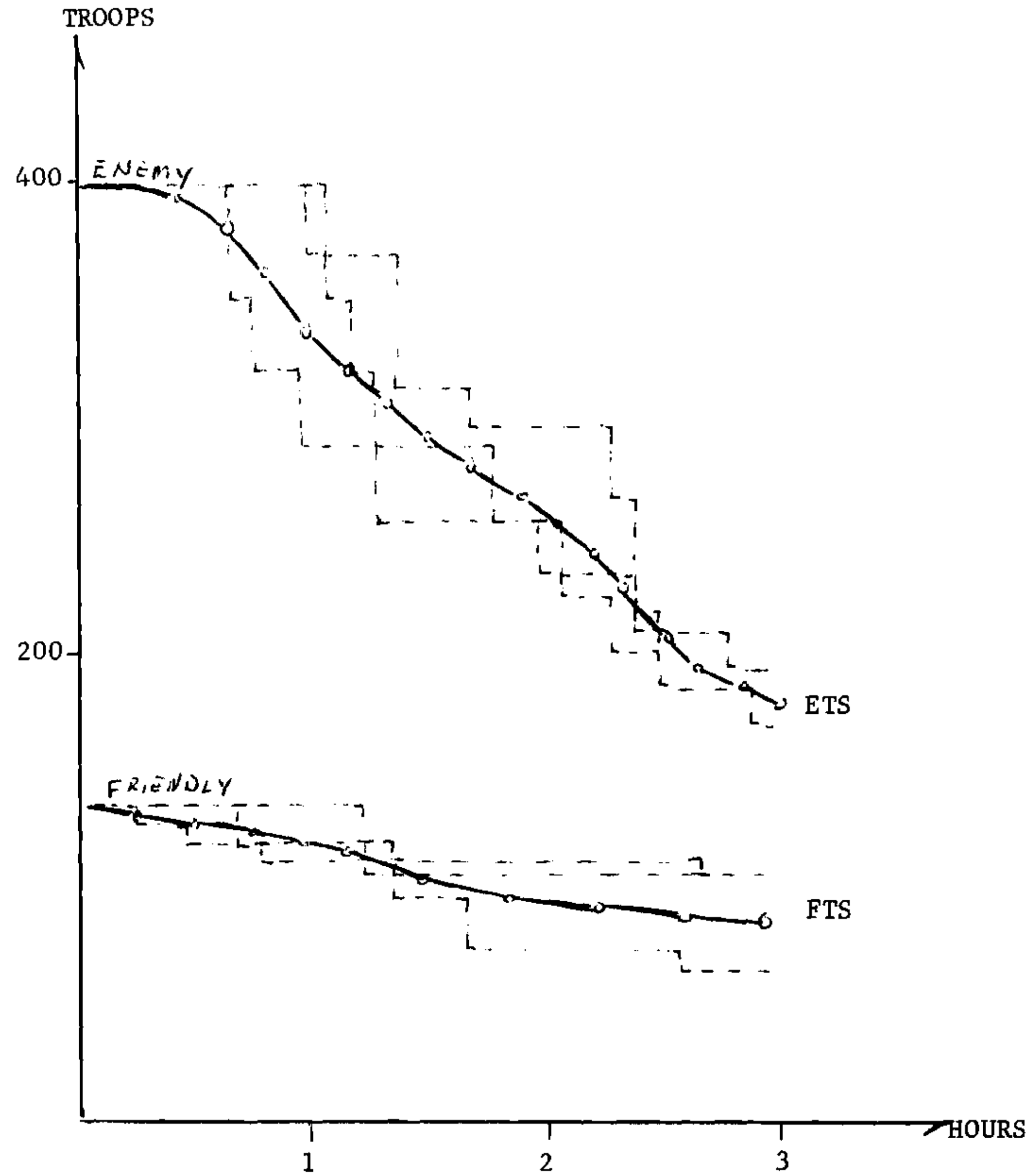


Figure 37. Validation Runs (Defense)

of this size to compute the actual operating costs. Let us approximate the cost constraint by using initial equipment costs. Since the rate of increase of initial costs increases as weapons range increases and the services organization increases in the same way, this should be an acceptable assumption. The initial costs (24) as of 1 November 1971 for one complete weapon of each type are as follows.

Table 3. Initial Costs for Selected Weapons

60 mm Mortar	635.00
81 mm Mortar	2,333.00
4.2 inch Mortar	5,212.00
105 mm Mortar	21,254.00

The total value of the three 81 mm mortars, four 4.2 inch mortars, and six 105 mm howitzers in the present system is $152,120. The 60 mm mortar is not considered because the present organization does not include 60 mm mortars. So, the extreme mixes within this constraint are either 250 each 60 mm mortars or 65 each 81 mm mortars, or 29 each 4.2 inch mortars, or 7 each 105 mm howitzers.

The crews for each weapon (22) are given below.

Table 4. Crew Strengths for Selected Weapons

60 mm Mortar	4
81 mm Mortar	6
4.2 inch Mortar	7
105 mm howitzer	9

The total personnel strength to serve all the weapons in the current organization model is 136. The extreme mixes allowable within the personnel constraint are: 34 each 60 mm mortars, or 22 each 81 mm mortars, or 19 each 4.2 inch mortars, or 15 each 105 mm howitzers.

The combination of both of the above constraints limit us to extremes of either: 34 each 60 mm mortars, or 22 each 81 mm mortars, or 19 each 4.2 inch mortars, or 7 each 105 mm howitzers. In order to best evaluate the discriminatory ability of the simulation let us select one extreme mix and two mixes which represent only a small variation from the present mix.

For the extreme example let us test the all 60 mm mortar alternative at company level. Next let us try eliminating the 81 mm mortar and replacing it with 4.2 inch mortars at battalion level. For the final example mix let us remove two 4.2 inch mortars from the battalion and add 81 mm mortars to each company. Table 5 shows the test mixes.

Table 5. Test Weapons Mixes

60 mm	81 mm	4.2 inch	105 mm
34	0	0	0
0	0	8	6
0	4	2	6

Results

Because of extreme limitation in time to complete this study and some technical difficulties, there are only a few replications of each test and results had to be drawn from less than ideal data. It had been hoped that some information could be gained from comparisons of replications with identical random events, but this proved infeasible. Analysis of the following runs is therefore incomplete.

The All 60 mm Mix

Only two replications of this run are available, but, because runs with identical random data can be compared, it was hoped some conclusions could be reached. The results expected intuitively from a mix of this extreme nature are that heavier enemy losses would be caused early because of the heavy fire power initially available on the enemy troop target, followed by lighter enemy losses and heavier friendly losses in the later time periods because the 60 mm mortars do not have the range to destroy enemy indirect fire weapons, but will themselves suffer attrition. The computer results shown in Figures 38 and 39 are somewhat disappointing. Because the time spacing of losses is dependent on the random variables losses in the base and test mixes occur at the same time. We are therefore unable to compare the earliness of losses directly. Comparison of mean values for many replications should show this relationship. When the loss does occur however, it is greater for the earlier event in the test mix. This agrees with our expectations. An unexplained result is the early higher losses for the friendly target in both replications. The deviation in behavior of this mix from the base mix is also not as severe as might be expected. Again, comparison of mean curves would probably be more productive. The expected behavior must be reexamined, of course, but it seems more likely that this is some, as yet, unfound error in the computer program.

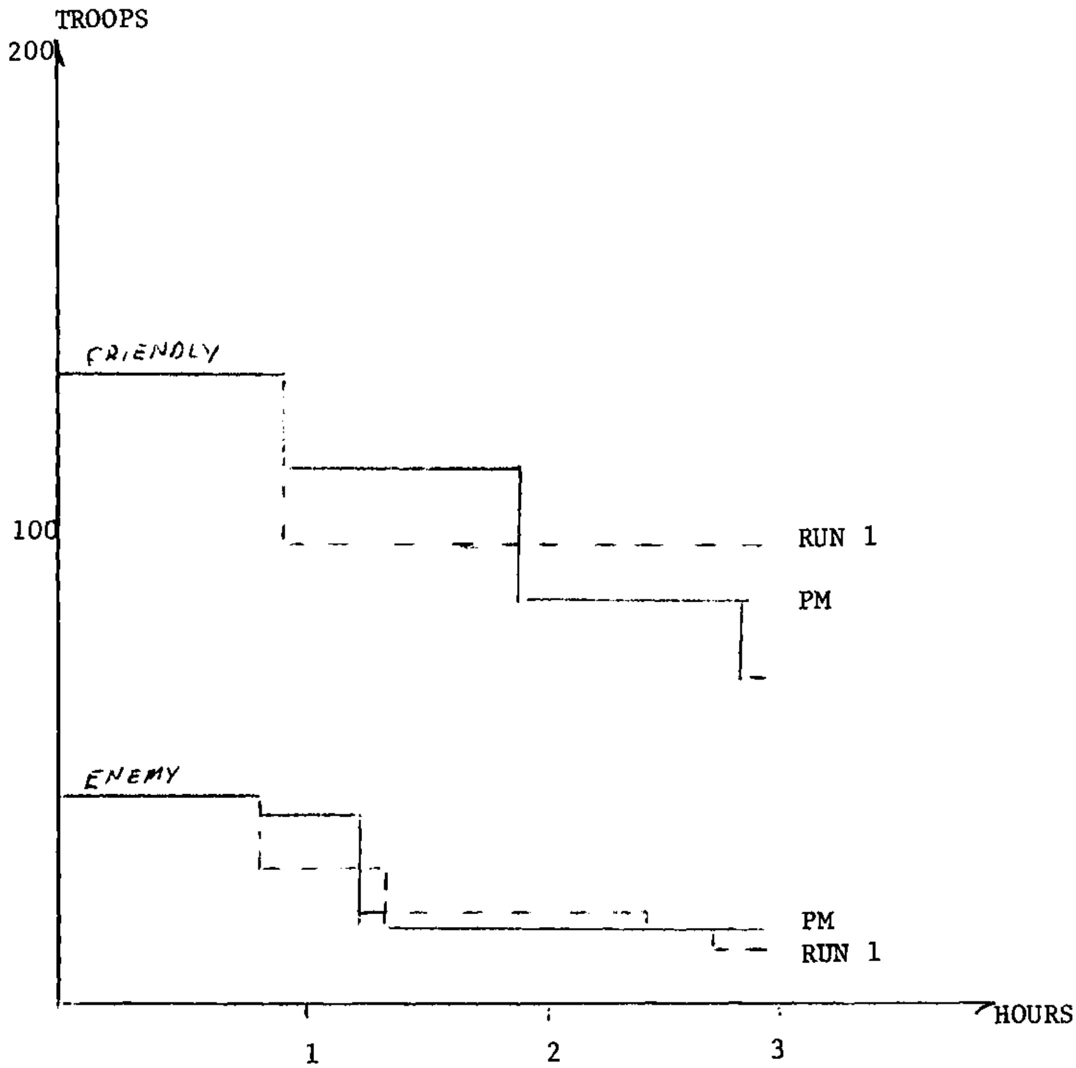


Figure 38. All 60 mm Mix, Run 1

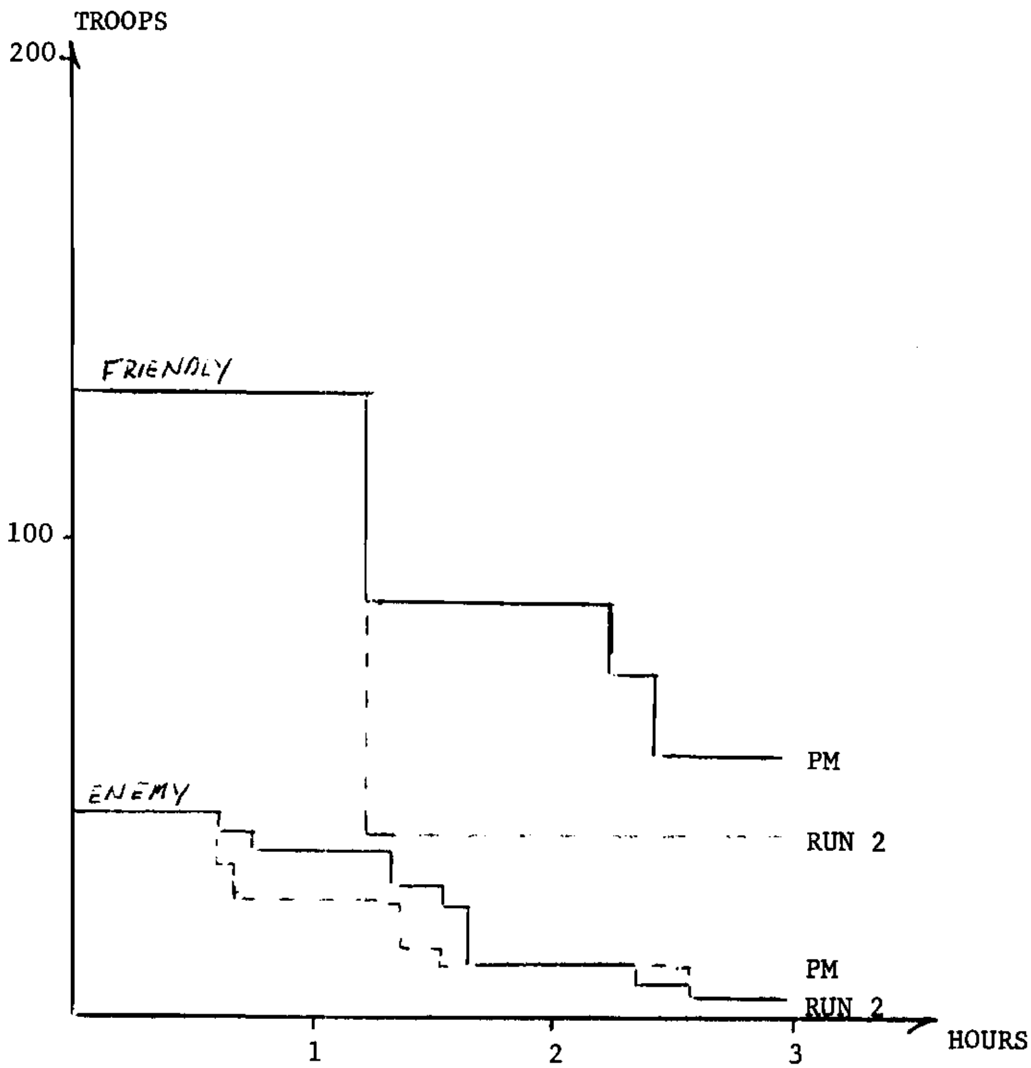


Figure 39. All 60 mm Mix, Run 2

The Increased 81 mm Mix

This mix substitutes an added 81 mm mortar at company level for two less 4.2 inch mortars at battalion level. Intuitively we should expect slightly increased early enemy losses and slightly decreased late enemy losses because quick reaction is substituted for range. Figures 40, 41, and 42 show the three replications of this mix available. In these runs increased early enemy losses do not appear, but decreased late enemy losses do appear. Friendly loss changes are contradictory. In two runs the initial losses are greater, but in the third the initial loss is less.

The Increased 4.2 Inch Mix

This mix substitutes an additional four 4.2 inch mortars at battalion level for all 81 mm mortars at company level. The expected effect of this change is the substitution of increased fire power at medium ranges for a decreased quick reaction capability. Enemy troop losses should be less at early times and greater at later times. Friendly troop losses should be unchanged early and less at later time.

Again the few replications (see Figures 43-46) are not very consistent. Early enemy losses are unchanged or less for all four replications but late enemy losses are contradictory. Early friendly losses are all greater than expected, but late friendly losses are uniformly less as expected.

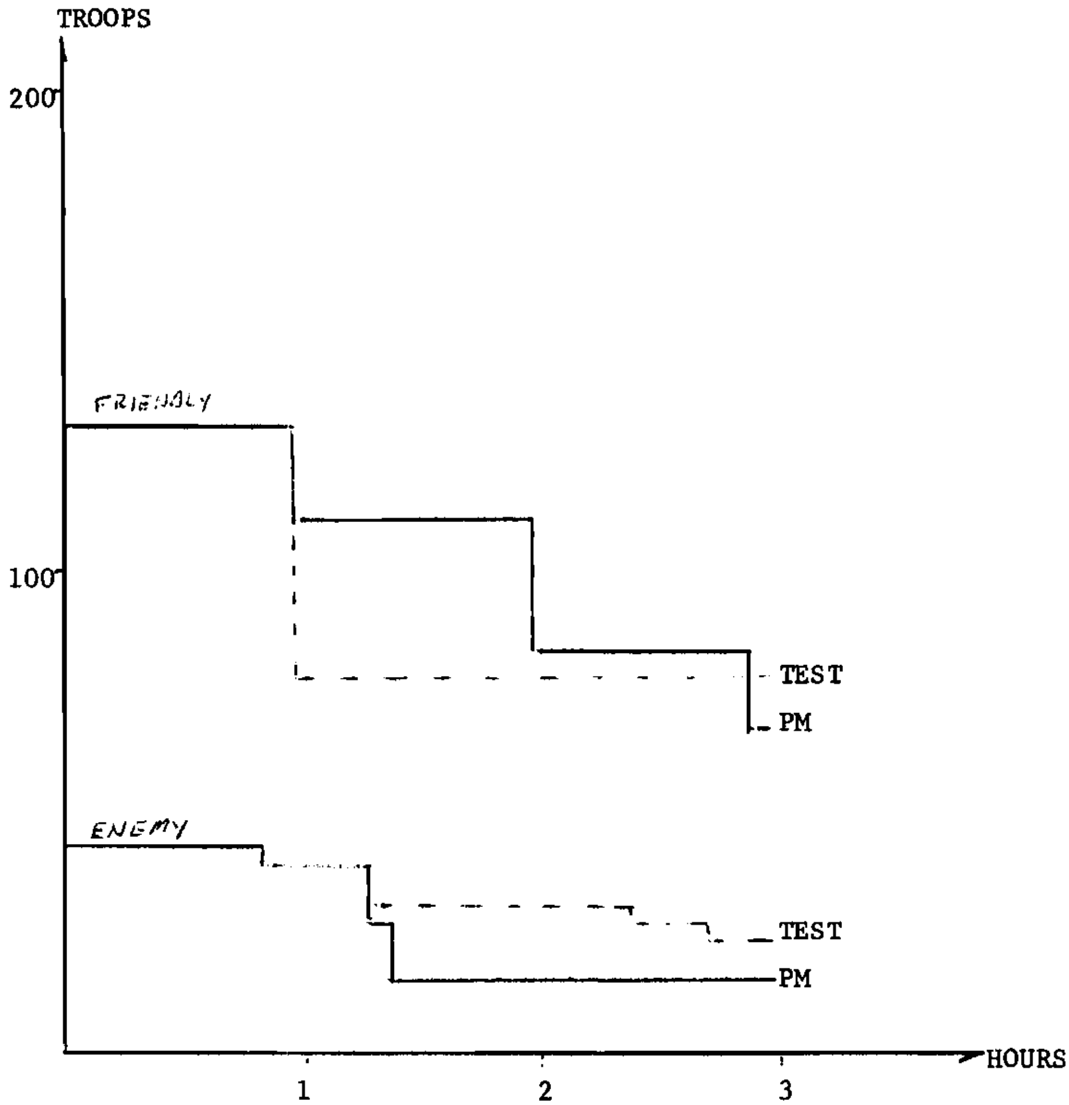


Figure 40. Increased 81 mm Mix, Run 1

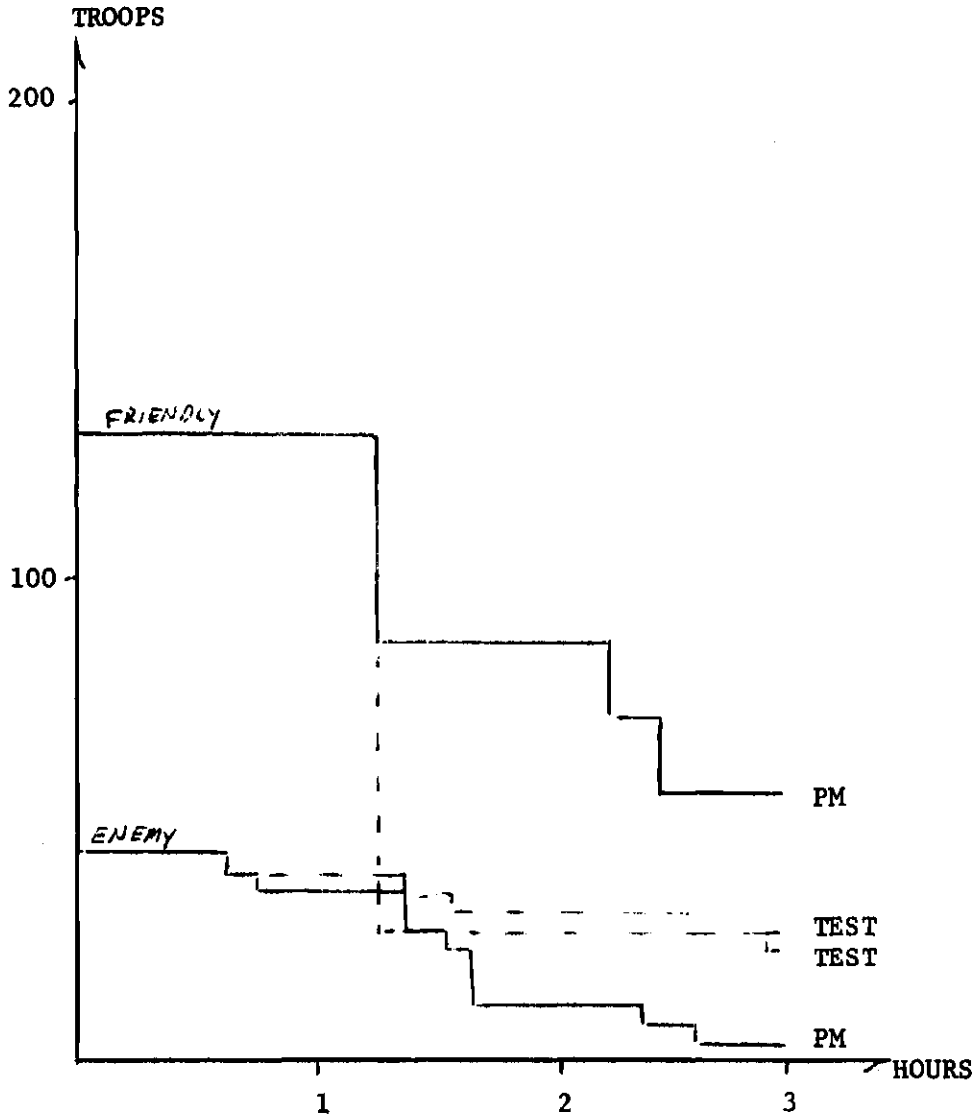


Figure 41. Increased 81 mm Mix, Run 2

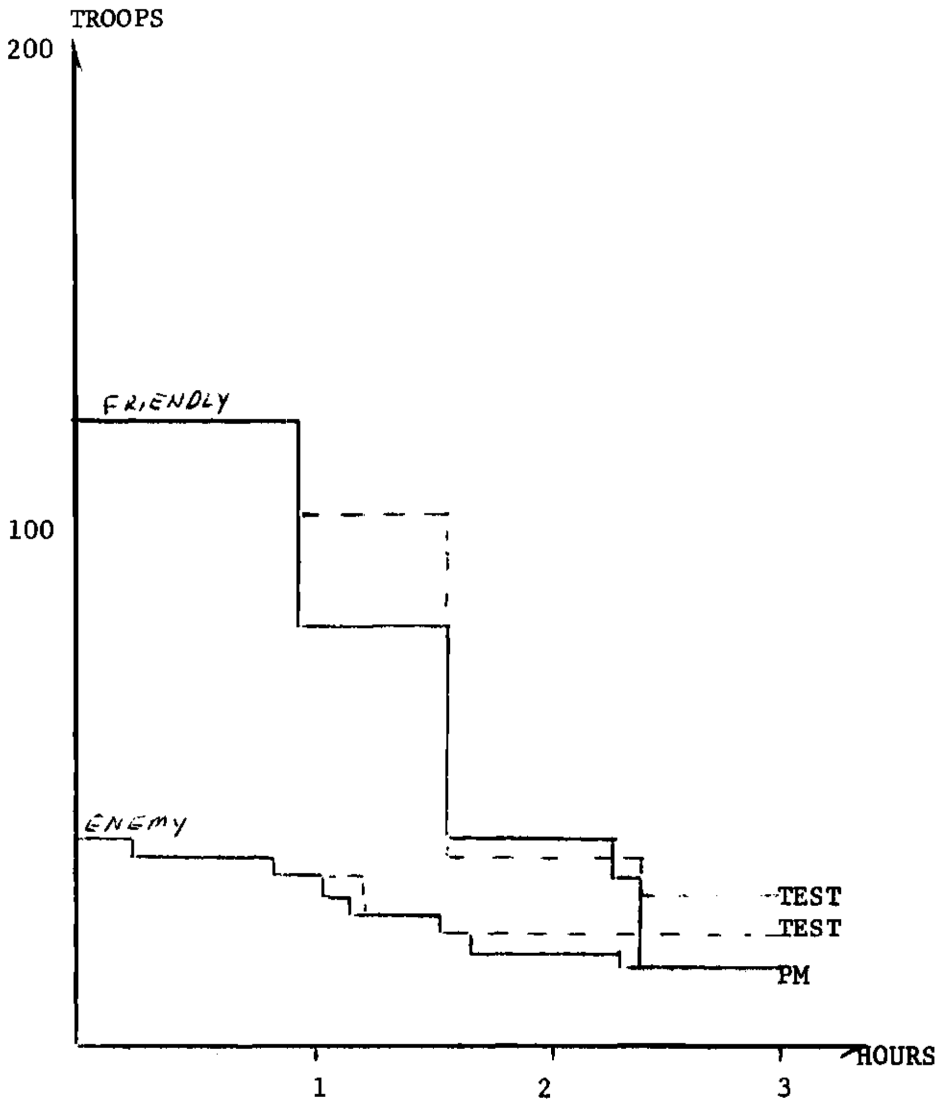


Figure 42. Increased 81 mm Mix, Run 3

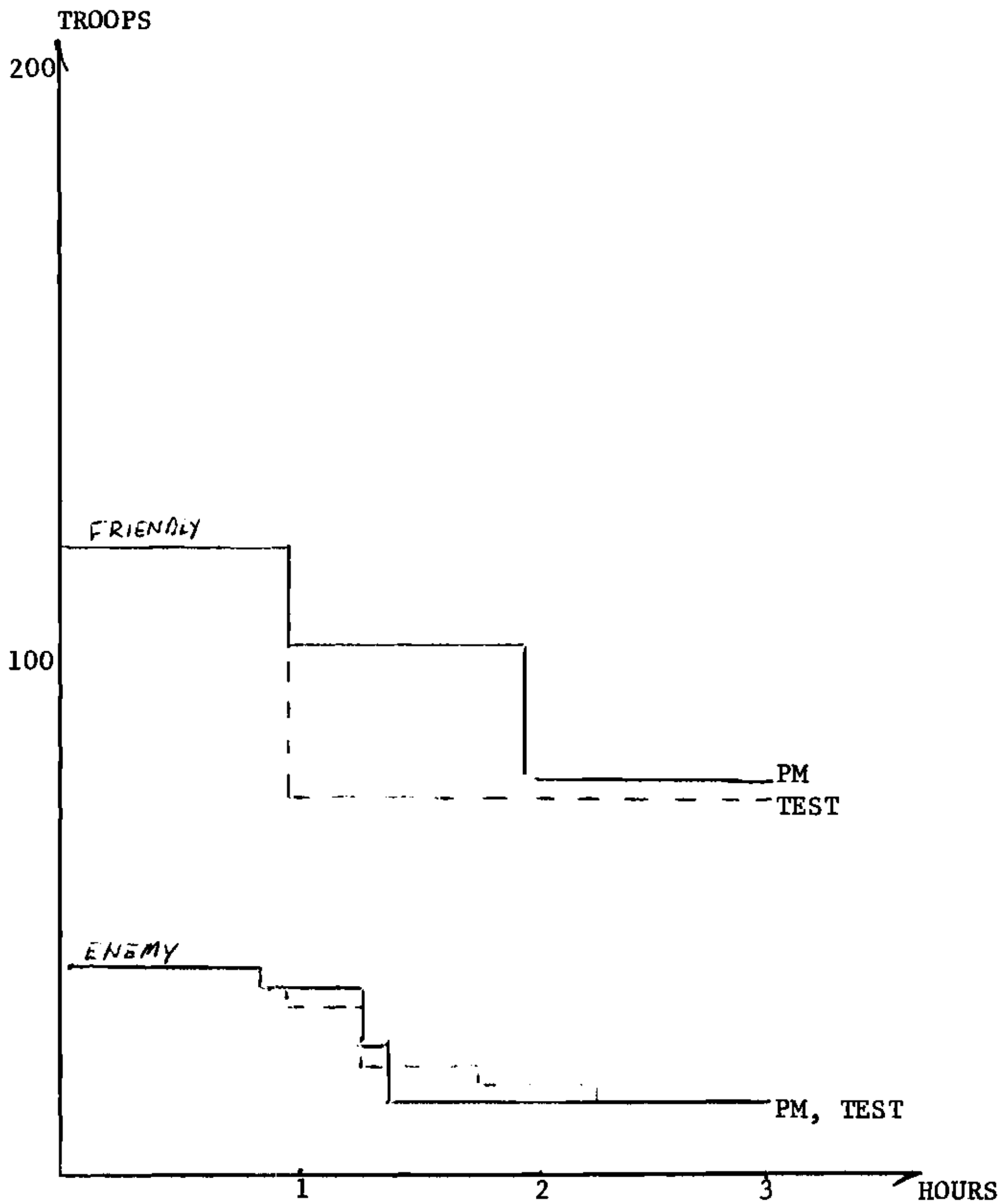


Figure 43. Increased 4.2 Inch Mix, Run 1

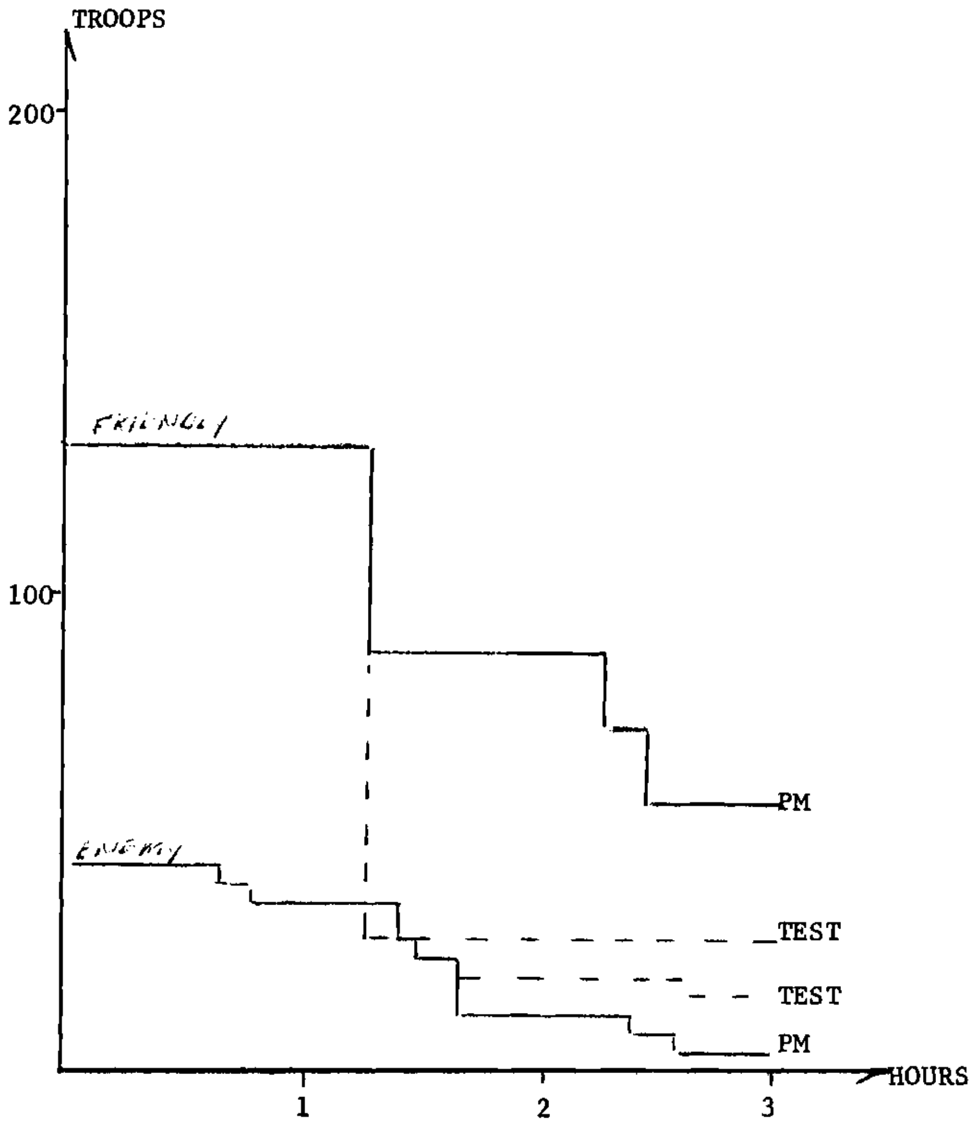


Figure 44. Increased 4.2 Inch Mix, Run 2

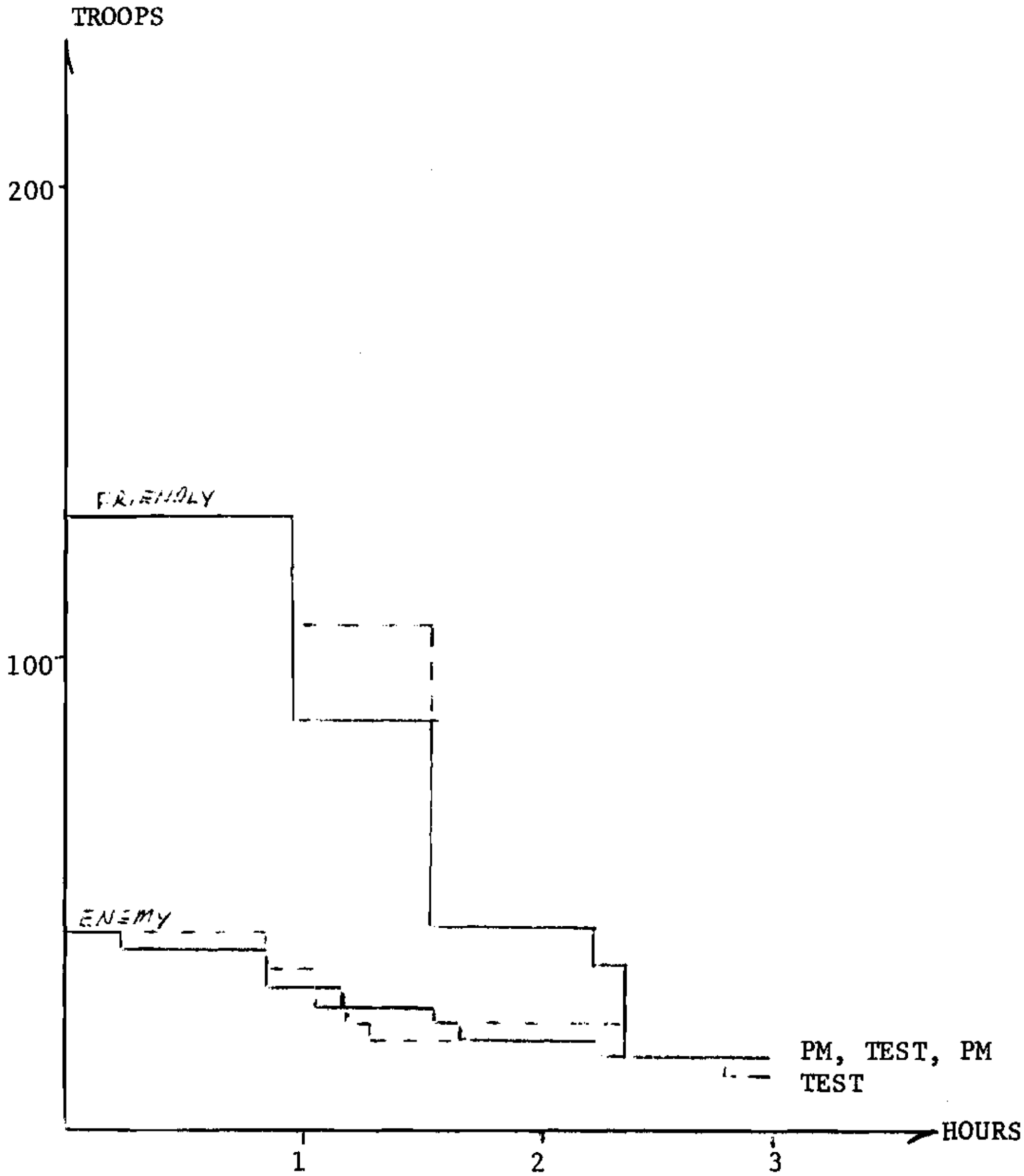


Figure 45. Increased 4.2 Inch Mix, Run 3

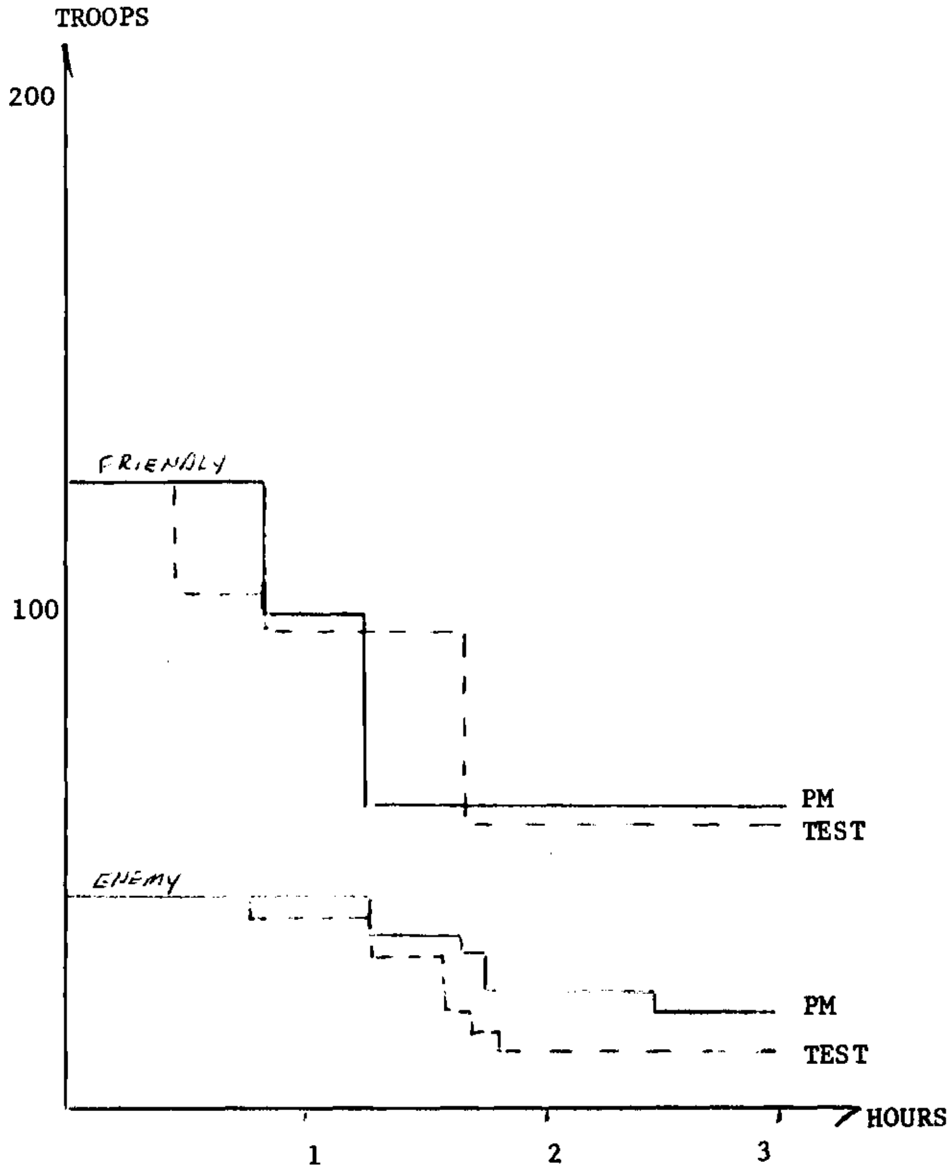


Figure 46. Increased 4.2 Inch Mix, Run 4

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It is apparent that comparison of mean curves representing many replications of each test mix must be made before any conclusion about the power of the model can be reached. Mean value curves could not be generated because of insufficient time.

It was hoped that comparison of test to base mix runs with identical random events would show significant trends. In the case of the two replications of the all 60 mm mix both showed the expected early larger losses and later smaller losses, but since there are only two replications this is not sufficient to define a trend. In all three replications of the increased 81 mm mix expected early larger losses in the enemy strength did not occur, but later lesser enemy losses did occur. Expected unchanged early friendly losses were supported by inconsistent initial loss changes. The variations among these initial loss values was greater than the variation among base mix replications of the same event, which suggests that random variation is greater than variation due to mix changes. Late losses were inconsistent for both friendly and enemy forces. While it appears that the model is sufficiently sensitive to troop strength to show variations in comparison of mixes with random values fixed, this sensitivity may not be sufficient to show significant changes when statistical analysis is applied to mean curves and their variances. If this is the case then improved resolution may solve the problem, but a large variance in the frequency and values of events such as weapons hits and troop kills is strongly supported by experience and military training.

Because DYNAMO provides an opportunity to compare replications where each replication has fixed random events for all mixes, the unusual opportunity to compare changes which are less than statistically significant is afforded. Although it would be very tedious to do so, individual comparison of each replication may be necessary if statistical significances cannot be shown. In this case, because the concept of statistical significance is overridden by this unique capability of DYNAMO, any trends which appear at that level should be seriously considered.

Limitations

While this simulation may provide a dynamic capability not available in other military models, it will have limitations because of scope, resolution, and purpose. This model was developed to meet a specific need of the Infantry Board. Because of this modification would be necessary to apply the model to an armor problem, for example. Low resolution primarily takes the form of crude approximations for the random variables. Since these random variables do have a highly significant effect on strength levels, their crude nature is an important limitation. These approximations were accepted by the author, in part, because of a lack of time to complete the work, but also because of the many gaps in necessary data. The provision of accurate data on decision delay times and other information of this nature would contribute to the need for better resolution in the model.

A much greater limitation of this model is the inability to consider varying tactics and intangibles such as esprit. Were consideration of these factors to be made, however, the model would probably increase in complexity three fold.

Recommendations

This study should be continued to obtain a conclusion with respect to the ability of the model to compare various weapons mixes. Sufficient reruns should be made to conduct a statistical analysis. If effectiveness cannot be measured statistically based on mean value curves, then comparison of mixes by individual replication should be made.

If the maximum potential of this model is to be realized, then accurate information on decision delay times, weapons service times, resupply times, and other organizational variables must be made available. Since this kind of information is necessary to any dynamic study, a general effort should be made by the defense community to gather and distribute this kind of information.

In this model tactics were fixed and organizational structure was allowed to vary. It should be possible and highly interesting to hold organization steady and vary tactics. If this could be done while maintaining compatability with this model, then a considerably more useful model would result. A dynamic model with this range of capabilities should be particularly useful in studying the relationship between maneuver speed and fire power which Bonder discusses (20).

It is most difficult to account for the effect of such factors as esprit on military organizations. Representation of the effects of morale, or esprit seems plausible in terms of varying degrees of positive and negative feedback. Such a study would probably be highly exploratory, but even the crudest quantitative representation of these intangibles might be of great value if only in providing a conceptual structure for further investigation.

APPENDICES

APPENDIX A

MISSION FLOW EQUATIONS

```
A DYNAMIC MODEL OF A FIRE SUPPORT BATTLE

        ENEMY MISSION FLOW

1L      EMD.K=FMD.J+(DT)(EMDR.JK-0)
20R     EMDR.KL=CEMIP.K/EMCT.K
7A      CEMIP.K=EMIP.K-EMIP.J
12A     EADL.K=(SMTA.K)(EN1.K)
8A      SMTA.K=TA.K+TS.K+TF.K
7A      EN1.K=EN.K-1
6A      TA.K=0.04
51A     TS.K=CLIP(0,0.1,RANDO.K,150)
20A     TF.K=RATF.K/VF.K
51A     VF.K=CLIP(3100,1000,RAHM.K,MXHM)
51A     RATF.K=CLIP(RAHM.K,RAG.K,RAHM.K,MXHM)
51A     EN.K=CLIP(N1.K,N2.K,RANDO.K,650)
51A     N1.K=CLIP(1,2,RANDU.K,667)
51A     N2.K=CLIP(3,N3.K,RANDU.K,600)
51A     N3.K=CLIP(4,5,RANDU.K,333)
33A     RANDU.K=500+(1000)NOISE
7A      EMCT.K=EADL.K+EVDL.K
7A      EVDL.K=TS.K+TFE.K
1L      EMIP.K=EMIP.J+(DT)(EMACR.JK-FMDR.JK)


20R     EMACR.KL=EMAC1.K/DT
54A     EMAC1.K=MIN(EUI.K,EMB.K)
7A      EUI.K=EUA.K-EMIP.K
1L      EMB.K=EMB.JK+(DT)(EMAR.JK-EMACR.JK)
20R     EMAR.KL=FUA.K/FACD
C       FACD=DT


FRIENDLY MISSION FLOW

1L      FMD.K=FMD.J+(DT)(FMDR.JK-0)
20R     FMDR.KL=(CFMIP.K)/FMCT.K
9A      FMCT.K=FADL.K+FVDL.K
7A      FVDL.K=TS.K+TF.K
19A     FADL.K=(FN1.K)(TA.K+TS.K+TFE.K+0)
7A      FN1.K=FN.K-1
51A     FN.K=CLIP(N1.K,N2.K,RANDU.K,650)
20A     TFE.K=RATE.K/VE.K
51A     RATE.K=CLIP(RAH.K,RA42.K,RA42.K,MX42)
51A     VE.K=CLIP(3100,1000,RA42.K,MX42)
7A      CFMIP.K=FMIP.K-FMIP.J
1L      FMIP.K=FMIP.J+(DT)(FMACR.JK-FMDR.JK)
20R     FMACR.KL=FMAC1.K/DT
54A     FMAC1.K=MIN(FUI.K,FMB.K)
7A      FUI.K=FUA.K-FMIP.K
1L      FMB.K=FMB.J+(DT)(FMAR.JK-FMACR.JK)
20R     FMAR.KL=FUA.K/FACD
C       EACD=DT
```

APPENDIX B

AMMUNITION FLOW EQUATIONS

```
        ENEMY AMMUNITION LLEVEL
1L      EAELM.K=EAELM.J+(DT)(EAFLM.JK+0)

        LIGHT MORTAR AMMUNITION
52L     EALM.K=EALM.J+(DT)(EADLM.JK-EAFLM.JK-EADRL.JK+0)
21R     EAFLM.KL=(1/EMCT.K)(ENLM.K+WSHL.J)
49A     ENLM.K=SWITCH(0,EN.K,EMPLM.K)
6R      EADRL.KL=0
39R     EADLM.KL=DELAY3(EARLM.JK,EASDL)
C       EASDL=6
26R     EARLM.KL=(EARLM.JK+EDLLM-EALM.J)/(DILM.K+0+0)
6A      EDLLM.K=300
20A     DILM=2
        HEAVY MORTAR AMMUNITION

1L      EAEHM.K=EAEHM.J+(DT)(EAFHM.JK-0)
1L      EAHM.K=EAHM.J+(DT)(EADHM.JK-EAFHM.JK)
21R     EAFHM.KL=(1/EMCT.K)(ENHM.K+WSHM.J)
49A     ENHM.K=SWITCH(0,EN.K,EMPHM.K)
6R      EADRLM.KL=0
39R     EADHM.KL=DELAY3(EARHM.JK,EASDM)
C       EASDM=4
26R     EARHM.KL=(EARHM.JK+EDLHM-EAHM.J)/(DIHM.K+0+0)
6A      EDLHM.K=300
20A     DIHM=2

        GUN-HOW AMMUNITION
1L      EAEG.K=EAEG.J+(DT)(EAFG.JK-0)
52L     EAG.K=EAG.J+(DT)(EADG.JK-EAFG.JK-EADRG.JK+0)
21R     EAFG.KL=(1/EMCT.K)(ENG.K+WSG.J)
49A     ENG.K=SWITCH(0,EN.K,EMPG.K)
6R      EADRG.KL=0
39R     EADG.KL=DELAY3(EARG.JK,EASDG)
C       EASDG=3


26R     EARG.KL=(EARG.JK+EDLG-EAG.J)/(DIG.K+0+0)
6A      EDLG.K=300
20A     DIG=2
```

FRIENDLY AMMUNITION LEVEL

```
        60MM MORTAR AMMUNITION
1L      FAE60.K=FAE60.J+(DT)(FAF60.JK-0)
26R     FAR60.KL=(FAF60.JK+FDL60-FA60.J)/(DI60.K+0+0)
52L     FA60.K=FA60.J+(DT)(FAD60.JK-FAF60.JK-FADR6.JK+0)
21R     FAF60.KL=(1/FMCT.K)(FN60.K+WSH60.J)
49A     FN60.K=SWITCH(0,FN.K,FMP60.K)
6R      FADR6.KL=0
39R     FAD60.KL=DELAY3(FAR60.JK,FASD6)
6A      FASD6=6
C       FDL60=300
26R     FAR81.KL=(FAF81.JK+FDL81-FA81.J)/(DI81.K+0+0)
6A      DI60=2

        81MM  AMMUNITIUN
1L      FAE81.K=FAE81.J+(DT)(FAF81.JK-0)
52L     FA81.K=FA81.J+(DT)(FAD81.JK-FAF81.JK-FADR8.JK+0)
21R     FAF81.KL=(1/FMCT.K)(FN81.K+WSH81.J)
49A     FN81.K=SWITCH(0,FN.K,FMP81.K)
6R      FADR8.KL=0
39R     FAD81.KL=DELAY3(FAR81.JK,FASD8)
C       FASD8=6
6A      FDL81=300
20A     DI81=2

        4.2 IN AMMUNITION
26R     FAR42.KL=(FAF42.JK+FDL42-FA42.J)/(DI42.K+0+0)
1L      FAE42.K=FAE42.J+(DT)(FAF42.JK-0)
52L     FA42.K=FA42.J+(DT)(FAD42.JK-FAF42.JK-FAD42.JK)
21R     FAF42.KL=(1/FMCT.K)(FN42.K+WSH42.J)
49A     FN42.K=SWITCH(0,FN.K,FMP42.K)
6R      FADR4.KL=0
39R     FAD42.KL=DELAY3(FAR42.JK,FASD4)
C       FASD4=4
6C      FDL42=300
20A     DI42=2

        HOWITZER AMMUNITION
26R     FARH.KL=(FAFH.JK+FDLH-FAH.J)/(DIH.K+0+0)
1L      FAEH.K=FAEH.J+(DT)(FAFH.JK-0)
52L     FAH.K=FAH.J+(DT)(FADH.JK-FAFH.JK-FADRH.JK+0)
21R     FAFH.KL=(1/FMCT.K)(FNH.K+WSHH.J)
49A     FNH.K=SWITCH(0,FN.K,FMPH.K)
6R      FADRH.KL=0
39R     FADH.KL=DELAY3(FARH.JK,FASDH)
C       FASDH=3
C       FDLH=300
20A     DIH=2
```

APPENDIX C

UNIT ACTIVITY LEVEL EQUATIONS

```
        FRIENDLY ACTIVITY LEVEL
51A     FUA.K=FUA.J+(DT)(FUAI.JK-FUO.JK)
51R     FUAI.KL=CLIP(FUA1.JK,0,FMB.J,FUA.J)
51R     FUA1.KL=CLIP(FUI2.JK,0,4,FUA.J)
        FUI2.KL=2
51R     FUO.KL=CLIP(0,FUO1.JK,FMB.J,FUA.J)
51R     FUO1.KL=CLIP(0,FUO2.JK,1,FUA.J)
39R     FUO2.KL=2
```

```
        ENEMY ACTIVITY LEVEL

1L      EUA.K=EUA.J+(DT)(EUAI.JK-EUO.JK)
51R     EUAI.KL=CLIP(FUA1.JK,0,EMB.J,FUA.J)
51R     EUA1.KL=CLIP(EUA2.JK,0,4,EUA.J)
        EUA2.KL=2
51R     EUO.KL=CLIP(0,EUO1.JK,EMB.J,FUA.J)
51R     EUO1.KL=CLIP(0,EUO2.JK,1,EUA.J)
        EUO2.KL=2
```

APPENDIX D

WEAPONS STRENGTH LEVEL EQUATIONS

```
        ENEMY WEAPONS STRENGTH LEVELS

51A     EWLR.K=CLIP(FWLR1.K,0,FMP.K,0)
51A     EWLR1.K=CLIP(EWLR2.K,0,RANDO.K,800)
51A     EWLR2.K=CLIP(0,1,RANU.K,EWSR.K)
27A     EWSR.K=FMPSQ.K/ETSHQ.K
12A     FMPSQ.K=(FMP.K)(FMP.K)
14+     ETSHQ.K=FMPSQ.K+(ETSH.K)(ETSH.K)
51A     ETSH.K=CLIP(TSQLM.K,ETSH1.K,CALM.K,CALV.K)
51A     ETSH1.K=CLIP(TSQHM.K,TSQG.K,CAHM.K,CAG.K)
12+     TSQLM.K=(TSHLM.K)(EBDLM)
12A     TSQHM.K=(TSHHM.K)(EBDHM)
12A     TSQG.K=(TSHG.K)(EBDG)
7A      CALM.K=EAELM.K-EAELM.J
7A      CAHM.K=EAEHM.K-EAEHM.J
7A      CAG.K=EAEG.K-EAEG.J
29R     EWRR.KL=DELAY3(EWLR.JK,12)
51A     TSHLL.K=CLIP(TSHLM.K,0,TSHLM.K,0)
1L      TSHLM.K=TSHLM.J+(DT)(LMRR.JK-LMLR.JK)
20R     LMLR.KL=LMLR1.K/DT
51A     LMLR1.K=CLIP(LML1.K,0,CALM.K,CAHM.K)
51A     LML1.K=CLIP(FWLR.K,0,CALM.K,CAG.K)
49R     LMRR.KL=SWITCH(0,EWRR.JK,LMLR.JK)
51A     TSHMH.K=CLIP(TSHHM.K,0,TSHHM.K,0)
1L      TSHHM.K=TSHHM.J+(DT)(LMRR.JK-LMLR.JK)
20R     HMLR.KL=HMLR1.K/DT
51A     HMLR1.K=CLIP(HML1.K,0,CAHM.K,CALM.K)
51A     HML1.K=CLIP(EWLR.K,0,CAHM.K,CAG.K)
49R     HMRR.KL=SWITCH(0,FWRR.JK,HMLR.JK)
51A     TS1G.K=CLIP(TSHG.K,0,TSHG.K,0)
1L      TSHG.K=TSHG.J+(DT)(GRR.JK-GLR.JK)
20R     GLR.KL=GLR11.K/DT
51A     GLR11.K=CLIP(GL1.K,0,CAG.K,CALM.K)
51A     GL1.K=CLIP(EWLR.K,0,CAG.K,CAHM.K)
49R     GRR.KL=SWITCH(0,EWRR.JK,GLR.JK)
7A      RANU.K=(0.5)+RNU.K
33A     RNU.K=(1)NOISE
```

```
        FRIENDLY WEAPONS STRENGTH LEVEL
51A     FWLR.K=CLIP(FWLR1.K,0,EMP.K,0)
51A     FWLR1.K=CLIP(FWLR2.K,0,RANDO.J,800)

51A     FWLR2.K=CLIP(0,1,RANU.J,FWSR.K)
27A     FWSR.K=EMPSQ.K/FTSHQ.K
12A     EMPSQ.K=(EMP.K)(EMP.K)
14A     FTSHQ.K=EMPSQ.K+(FTSH.K)(FTSH.K)
51A     FTSH.K=CLIP(TSQ60.K,FTSH1.K,CA60.K,CA6V.K)
51A     FTSH1.K=CLIP(TSQ81.K,FTSH2.K,CA81.K,CA8V.K)
51A     FTSH2.K=CLIP(TSQ42.K,TSQH.K,CA42.K,CAH.K)
12A     TSQ60.K=(TSH60.K)(FBD60)
12A     TSQ81.K=(TSH81.K)(FBD81)
12A     TSQ42.K=(TSH42.K)(FBD42)
12A     TSQH.K=(TSHH.K)(FBDH)
39R     FWRR.KL=DELAY3(FWLR.JK,12)
51A     TSH61.K=CLIP(TSH60.K,0,TSH60.K,0)
1L      TSH60.K=TSH60.J+(DT)(R60R.JK-R60L.JK)
49R     R60R.KL=SWITCH(0,FWRR.JK,R60L.JK)
20R     R60L.KL=R611.K/DT
51A     R611.K=CLIP(R61L.K,0,CA60.K,CA81.K)
51A     R61L.K=CLIP(R62L.K,0,CA60.K,CA42.K)
51A     R62L.K=CLIP(FWLR.K,0,CA60.K,CAH.K)
51A     TSH82.K=CLIP(TSH81.K,0,TSH81.K,0)
1L      TSH81.K=TSH81.J+(DT)(R81R.JK-R81L.JK)
49R     R81R.KL=SWITCH(0,FWRR.JK,R81L.JK)
20R     R81L.KL=R811.K/DT
51A     R811.K=CLIP(R82.K,0,CA81.K,CA60.K)
51A     R82.K=CLIP(R83.K,0,CA81.K,CA42.K)
51A     R83.K=CLIP(FWLR.K,0,CA81.K,CAH.K)
51A     TSH43.K=CLIP(TSH42.K,0,TSH42.K,0)
1L      TSH42.K=TSH42.J+(DT)(R42R.JK-R42L.JK)
49R     R42R.KL=SWITCH(0,FWRR.JK,R42L.JK)
20R     R42L.KL=R422L.K/DT
51A     R422L.K=CLIP(R43.K,0,CA42.K,CA60.K)
51A     R43.K=CLIP(R44.K,0,CA42.K,CA81.K)
51A     R44.K=CLIP(FWLR.K,0,CA42.K,CAH.K)
51A     TSH1.K=CLIP(TSHH.K,0,TSHH.K,0)
1L      TSHH.K=TSHH.J+(DT)(RHR.JK-RHL.JK)
49R     RHR.KL=SWITCH(0,FWRR.JK,RHL.JK)
51A     RH1.K=CLIP(RH2.K,0,CAH.K,CA81.K)
51A     RH2.K=CLIP(FWLR.K,0,CAH.K,CA42.K)
20R     RHL.KL=RH11.K/DT
51A     RH11.K=CLIP(RH1.K,0,CAH.J,CA60.K)
7A      CA60.K=FAE60.K-FAE60.J
7A      CA81.K=FAE81.K-FAE81.J
7A      CA42.K=FAE42.K-FAE42.J
7A      CAH.K=FAEH.K-FAEH.J
```

APPENDIX E

TROOP STRENGTH LEVEL EQUATIONS

```
        FRIENDLY TROOP STRENGTH LEVEL

51A     FTS.K=CLIP(FT1.K,0,FT1.K,0)
1L      FT1.K=FT1.J+(DT)(FTRR.JK-FTLR.JK)
6R      FTRR.KL=0
44R     FTLR.KL=(EMET.K)(FTD.J)/DT
13A     EMET.K=(FE.K)(EMP.K)(PFTK.K)


        ENEMY TROOP STRENGTH LEVEL

51A     ETS.K=CLIP(ET1.K,0,ET1.K,0)
1L      ET1.K=ET1.J+(DT)(ETRR.JK-ETLR.JK)
6R      ETRR.KL=0
44R     ETLR.KL=(FMET.K)(ETD.K)/DT
13A     FMET.K=(EL.K)(FMP.K)(PETK.K)
```

APPENDIX F

MISSION POTENTIAL EQUATIONS

```
        ENEMY MISSION POTENTIAL

8A      FMP.K=FMPLM.K+EMPHM.K+EMPG.K
12A     EMPLM.K=(WSHL.K)(EBDLM)
        EMPHM.K=(WSHM.K)(EBDHM)(.5)
12A     EMPG.K=(WSG.K)(EBDG)(.6)
49A     WSHL.K=SWITCH(0,ASHL.K,RFLM.K)
49A     WSHM.K=SWITCH(0,ASHM.K,RFHM.K)
49A     WSG.K=SWITCH(0,ASHG.K,RFG.K)
51A     ASHL.K=CLIP(0,MSHLM.K,MSHLM.K,EALM.K)
51A     ASHM.K=CLIP(0,MSHHM.K,MSHHM.K,EAHM.K)
51A     ASHG.K=CLIP(0,MSHG.K,MSHG.K,EAG.K)
49A     MSHLM.K=SWITCH(USHLM.K,USHL2.K,VELLM.K)
20A     USHL2.K=USHLM.K/2
49A     MSHHM.K=SWITCH(USHHM.K,USHM2.K,VELHM.K)
20A     USHM2.K=USHHM.K/2
49A     MSHG.K=SWITCH(USHG.K,USHG2.K,VELG.K)
20A     USHG2.K=USHG.K/2
51A     USHLM.K=CLIP(TSHLL.K,TSHL2.K,FUA.K,2)
20A     TSHL2.K=TSHLL.K/2
51A     USHHM.K=CLIP(TSHMH.K,0,EUA.K,3)
51A     USHG.K=CLIP(TS1G.K,0,EUA.K,3)
7C      EBDLM=20
7C      EBDHM=40
7C      EBDG=25
51A     RFLM.K=CLIP(1,0,MXLM,RALM.K)
51A     RFHM.K=CLIP(1,0,MXHM,RAHM.K)
51A     RFG.K=CLIP(1.0,MXG,RAG.K)
        FRIENDLY MISSIUN POTENTIAL

9A      FMP.K=FMP60.K+FMP81.K+FMP42.K+FMPH.K+1
12A     FMP60.K=(ASH60.K)(FBD60)
        FMP81.K=(ASH81.K)(EBD81)(.6)
        FMP42.K=(ASH42.K)(FBD42)(.7)
        FMPH.K=(ASHH.K)(EBDH)(.8)
49A     WSH60.K=SWITCH(0,ASH60.K,RF60.K)
49A     WSH81.K=SWITCH(0,ASH81.K,RF81.K)
49A     WSH42.K=SWITCH(0,ASH42.K,RF42.K)
49A     WSHH.K=SWITCH(0,ASHH.K,RFH.K)
51A     ASH60.K=CLIP(0,MSH60.K,MSH60.K,FA60.K)
51A     ASH81.K=CLIP(0,MSH81.K,MSH81.K,FA81.K)
51A     ASH42.K=CLIP(0,MSH42.K,MSH42.K,FA42.K)
51A     ASHH.K=CLIP(0,MSHH.K,MSHH.K,FAH.K)


49A     MSH60.K=SWITCH(USH60.K,USH62.K,VEL60.K)
20A     USH62.K=USH60.K/2
49A     MSH81.K=SWITCH(USH81.K,USH83.K,VEL81.K)
20A     USH83.K=USH81.K/2
49A     MSH42.K=SWITCH(USH42.K,USH45.K,VEL42.K)
20A     USH45.K=USH42.K/2
49A     MSHH.K=SWITCH(USHH.K,USHH2.K,VELH.K)
20A     USHH2.K=USHH.K/2
51A     USH60.K=CLIP(TSH61.K,0,FUA.K,1)
51A     USH81.K=CLIP(TSH82.K,0,FUA.K,1)
51A     USH42.K=CLIP(TSH43.K,0,FUA.K,2)
51A     USHH.K=CLIP(TSH1.K,0,FUA.K,3)
C       EBD60=18
C       EBD81=25
C       EBD42=40
C       EBDH=30
51A     RF60.K=CLIP(1,0,MX60,RA60.K)
51A     RF81.K=CLIP(1,0,MX81,RA81.K)
51A     RF42.K=CLIP(1,0,MX42,RA42.K)
51A     RFH.K=CLIP(1,0,MXH,RAH.K)
```

APPENDIX G

MISSION EFFECTIVENESS EQUATIONS

```
        FRIENDLY TROOP DENSITY FACTOR

20A     FTD.K=FTS.J/FDF.K
51A     FDF.K=CLIP(300,FDDF.K,SREF,0)
49A     FDDF.K=SWITCH(1200,1800,SSR)


        FRIENDLY EXPOSURE FACTOR

51A     FE.K=CLIP(FEA.K,FFD.K,SREF,0)
51A     FEA.K=CLIP(0.98,FE1.K,EMIP.K,1)
58A     FE1.K=TABHL(KILA,EADL,0,0.02,0.005)
C       KILA*=0.98/0/0.75/0.005/0.55/0.01/0.50/0.015/0.45/0.02
49A     FFD.K=SWITCH(FDL.K,FD.K,SSR)
58A     FDL.K=TABHL(KILDL,EADL,0,0.02,0.005)
C       KILDL*=0.50/0/0.27/0.005/0.26/0.01/0.26/0.015/0.25/0.02
C       FD.K=TABHL(KILD,EADL,0,0.02,0.005)
C       KILD*=0.50/0/0.15/0.005/0.13/0.01/0.12/0.015/0.11/0.02


        ENEMY TROOP DENSITY FACTOR

20A     ETD.K=ETS.J/EDF.K
51A     EDF.K=CLIP(900,EDDF.K,0,SREF)
49A     EDDF.K=SWITCH(400,600,SSR)


        ENEMY EXPOSURE FACTOR

51A     EE.K=CLIP(EEA.K,EDP.K,0,SREF)
51A     EEA.K=CLIP(0.98,EE1.K,EMIP.K,1)
58A     EE1.K=TABHL(KILA,FADL,0,0.02,0.005)
49A     EDP.K=SWITCH(EDL.K,DE.K,SSR)
58A     EDL.K=TABHL(KILDL,FADL,0,0.02,0.005)
58A     DE.K=TABHL(KILD,FADL,0,0.02,0.005)
```

```
        PROBABILITY OF FRIENDLY TROOP KILL

33A     RANDO.K=500+(1000)NOISE
6S      XXX.K=NOISE
12A     PFTK.K=(FPTAO.K)(PTFK.K)
51A     FPTAO.K=CLIP(SO.K,FS1.K,RANDO.K,200)
51A     FS1.K=CLIP(FSP.K,FSU.K,RANDO.K,444)
51A     FSP.K=CLIP(0.9,0.7,SREF,0)
51A     FSU.K=CLIP(0.5,0.4,SREF,0)
6A      SO.K=1
51A     PTFK.K=CLIP(0,PTF1.K,RANDO.J,800)
51A     PTF1.K=CLIP(0,PTF2A.K,ED.K,EFBD4.K)
20A     EEBD4.K=EEBD.K/4
20A     PTF2A.K=PTF2.K/EEBD.K
32A     PTF2.K=(EEBD.K)COS((2PI)(ED.K)/EEBD8.K)
        FEBD8.K=(EEBD.K)(4)
8A      EBFA.K=EBFLM.K+EBFHM.K+EBFG.K
24A     EEBD.K=EMP.K/EBFA.K
20A     EBFLM.K=EMPLM.K/EBDLM
20+     EBFHM.K=EMPHM.K/EBDHM
20A     EBFG.K=EMPG.K/EBDG
51A     ED.K=CLIP(EDD.K,-EDD.K,EDD.K,0)
34A     EDD.K=(1)NORMRN(0,ECEP.K)
12A     ECPLM.K=(CEPLM)(WSHL.K)
12A     ECPHM.K=(CEPHM)(WSHM.K)
12A     ECPG.K=(CEPG)(WSG.K)
24A     FCEP.K=(1/EBFA.K)(ECPLM.K+ECPHM.K+ECPG.K)
C       CEPLM=35
C       CEPHM=25
C       CEPG=25
        PROBABILITY OF ENEMY TROOP KILL

12A     PETK.K=(EPTAO.K)(PTEK.K)
51A     EPTAO.K=CLIP(SO.K,ES1.K,RANDO.K,200)
51A     ES1.K=CLIP(ESP.K,ESU.K,RANDO.K,444)
51A     ESP.K=CLIP(0.9,0.7,0,SREF)
51A     ESU.K=CLIP(0.5,0.4,0,SREF)
51A     PTEK.K=CLIP(0,PTE1.K,RANDO.K,800)
51A     PTE1.K=CLIP(0,PTE2A.K,DF.K,FFBD4.K)
20A     FEBD4.K=FEBD.K/4
20A     PTE2A.K=PTE2.K/FEBD.K
32A     PTE2.K=(FEBD.K)COS((2PI)(DF.K)/FEBD8.K)
        FEBD8.K=(FEBD.K)(4)
20A     FEBD.K=FMP.K/FBFA.K
20A     FBD60.K=FMP60.K/EBD60
20A     FBD81.K=FMP81.K/EBD81
20A     FBD42.K=FMP42.K/EBD42
20A     FBDH.K=FMPH.K/EBDH
9A      FBFA.K=FBD60.K+FBD81.K+FBD42.K+FBDH.K
51A     DF.K=CLIP(FDD.K,-FDD.K,FDD.K,0)



34A     FDD.K=(1)NORMRN(0,FCEP.K)
24A     FCEP.K=(1/FBFA.K)(FCP60.K+FCP81.K+FCP42.K+FCPH.K)
12A     FCP60.K=(CEP60)(WSH60.K)
12A     FCP81.K=(CEP81)(WSH81.K)
12A     FCP42.K=(CEP42)(WSH42.K)
12A     FCPH.K=(CEPH)(WSHH.K)
C       CEP60=20
C       CEP81=20
C       CEP42=15
C       CEPH=10
```

APPENDIX H

MOVEMENT AND TERRAIN EQUATIONS

```
        MOVEMENT AND TERRAIN SECTION
        TERRAIN
7A      TPZ.K=TZ+TPZZ.K
32A     TPZZ.K=(TZZ.K)COS((2PI)(1)/TPPP)
C       TZ=500
7A      TZZ.K=TROL+TRNDO.K
C       TROL=10
33A     TRNDO.K=(TRND)NOISE
C       TPPP=100
C       TRND=10
C       TAVZ=1000
        ROLE SWITCHES
C       SREF=1
C       SR=1
C       SSR=0
49A     ROLE.K=SWITCH(500,DROL,SR)
49A     DROL.K=SWITCH(100,0,SSR)
        FRIENDLY TARGET MOVEMENT
7N      FTG=X+9500
1L      FTG.K=FTG.J+(DT)(RTU.JK-0)
44R     RTU.KL=(SREF)(RTUU.K)/DT
51A     RTUU.K=CLIP(RTA1.K,FDP.K,SREF,0)
14A     RTA.K=ROL1.K+(ROL2.K)(SLFTG.K)
51A     RTA1.K=CLIP(100,RTA.K,460,MRA.K)
7RA     ROL1.K=1+ROLE.K
20A     ROL2.K=ROLE.K/2
31A     SLFTG.K=(-1)SIN((2PI)(FTG.J)/TPP)

51A     FDP.K=CLIP(RTA.K,TMC.K,MAR,MRA.K)
7A      MRA.K=ETG.K-FTG.K
49C     MAR=SWITCH(-20,460,SSR)
7A      ELFTG.K=ELEFT.K+TAVZ
32A     ELEFT.K=(TPZ.K)COS((2PI)(FTG.K)/TPP)
51A     TOP.K=CLIP(0,RTA.K,ELFTG.K,ELFTG.J)
51A     TMC.K=CLIP(TOP.K,RTA.K,ELFTG.K,TMZ.K)
44A     TMZ.K=(TMZZ.K)(7)/8
7A      TMZZ.K=TAVZ+TPZ.K
        ENEMY TARGET MOVEMENT
7N      ETG=X+10500
1L      ETG.K=ETG.J+(DT)(ERTU.JK-0)
44R     ERTU.KL=(SREF)(ERTUU.K)/DT
51A     ERTUU.K=CLIP(ERTA1.K,EFDP.K,0,SREF)
14A     ERTA.K=ROL1.K+(ROL2.K)(SLETG.K)
51A     ERTA1.K=CLIP(100,ERTA.K,460,MRA.K)
51A     EFDP.K=CLIP(ERTA.K,ETMC.K,MAR,MRA.K)
51A     ETMC.K=CLIP(ETOP.K,ERTA.K,ELETG.K,TMZ.K)
31A     SLETG.K=(-1)SIN((2PI)(ETG.J)/TPP)
7A      ELETG.K=ELEET.K+TAVZ
32A     ELEET.K=(TPZ.K)COS((2PI)(ETG.K)/TPP)
51A     ETOP.K=CLIP(0,ERTA.K,ELETG.K,ELETG.J)
```

```
        FRIENDLY WEAPONS MOVEMENT
7N      X60=X+9400
1L      X60.K=X60.J+(DT)(VEL60.JK-0)
44R     VEL60.KL=(SRFF)(VELL6.K)/DT
51A     VELL6.K=CLIP(0,VLL60.K,MD60.K,RD60.K)
51A     MD60.K=CLIP(MX603,RA60.K,SREF,0)
51A     RD60.K=CLIP(RA60.K,MX604,SREF,0)
44C     MX603=(3)(MX60)/4
20C     MX604=MX60/4
49A     VLL60.K=SWITCH(0,VL60.K,DSL60.K)
7A      DSL60.K=MX605-DSP60.K
44C     MX605=(MX60)(5)/12
1L      DSP60.K=DSP60.J+(DT)(VL60.JK-DMP60.JK)
20R     DMP60.KL=DMP61.K/DT
49A     DMP61.K=SWITCH(0,VLM60.K,DSP60.J)
12R     VLM60.KL=100000
14R     VL60.KL=AV602+(AV604)(SLX60.K)
20C     AV602=AV60/2
20C     AV604=AV60/4
31A     SLX60.K=(-1)SIN((2PI)(X60.J)/TPP)
C       AV60=500

7N      X81=X+9000
1L      X81.K=X81.J+(DT)(VEL81.JK-0)
44R     VEL81.KL=(SRFF)(VELL8.K)/DT
51A     VELL8.K=CLIP(0,VLL81.K,MD81.K,RD81.K)
51A     MD81.K=CLIP(MX813,RA81.K,SREF,0)
51A     RD81.K=CLIP(RA81.K,MX814,SREF,0)
44C     MX813=(3)(MX81)/4
20C     MX814=MX81/4
49A     VLL81.K=SWITCH(0,VL81.K,DSL81.K)
7A      DSL81.K=MX815-DSP81.K
44A     MX815=(MX81)(5)/12
1L      DSP81.K=DSP81.J+(DT)(VL81.JK-DMP81.JK)
20R     DMP81.KL=DMP82.K/DT
49A     DMP82.K=SWITCH(0,VLM81.K,DSP81.J)
12R     VLM81.KL=100000
14R     VL81.KL=AV812+(AV814)(SLX81.K)
20C     AV812=AV81/2
20C     AV814=AV81/4
31A     SLX81.K=(-1)SIN((2PI)(X81.J)/TPP)
C       AV81=500

7N      X42=X+8500
1L      X42.K=X42.J+(DT)(VEL42.JK-0)
44R     VEL42.KL=(SRFF)(VELL4.K)/DT
51A     VELL4.K=CLIP(0,VLL42.K,MD42.K,RD42.K)
51A     MD42.K=CLIP(MX423,RA42.K,SREF,0)
51A     RD42.K=CLIP(RA42.K,MX424,SREF,0)
44C     MX423=(3)(MX42)/4
20C     MX424=MX42/4
49A     VLL42.K=SWITCH(0,VL42.K,DSL42.K)
7A      DSL42.K=MX425-DSP42.K
44C     MX425=(MX42)(5)/12
1L      DSP42.K=DSP42.J+(DT)(VL42.JK-DMP42.JK)
20R     DMP42.KL=DMP43.K/DT
49A     DMP43.K=SWITCH(0,VLM42.K,DSP42.J)
12R     VLM42.KL=100000
14R     VL42.KL=AV422+(AV424)(SLX42.K)


20C     AV422=AV42/2
20C     AV424=AV42/4
31A     SLX42.K=(-1)SIN((2PI)(X42.J)/TPP)
C       AV42=700
```

```
7N      XH=X+8000
1L      XH.K=XH.J+(DT)(VELH.JK-0)
44R     VELH .KL=(SREF)(VELLH.K)/DT
51A     VELLH.K=CLIP(0,VLLH.K,MDH.K,RDH.K)
51A     MDH.K=CLIP(MXH3,RAH.K,SREF,0)
51A     RDH.K=CLIP(RAH.K,MXH4,SREF,0)
44C     MXH3=(3)(MXH)/4
20C     MXH4=MXH/4
49A     VLLH.K=SWITCH(0,VLH.K,DSLH.K)
7A      DSLH.K=MXH5-DSPH.K
44C     MXH5=(MXH)(5)/12
1L      DSPH.K=DSPH.J+(DT)(VLH.JK-DMPH.JK)
20R     DMPH.KL=DMPH.K/DT
12R     VLMH.KL=100000
14R     VLH.KL=AVH2+(AVH4)(SLXH.K)
20C     AVH2=AVH/2
20C     AVH4=AVH/4
31A     SLXH.K=(-1)SIN((2PI)(XH.J)/TPP)
C       AVH=700

        ENEMY WEAPONS MOVEMENT
7N      XLM=11000
1L      XLM.K=XLM.J+(DT)(VELLM.JK-0)
12R     VELLM.KL=(SRFF)(VELM.K)/DT
51A     VELM.K=CLIP(0,VLLM.K,MDLM.K,RDLM.K)
51A     MDLM.K=CLIP(MXLM3,RALM.K,0,SREF)
51A     RDLM.K=CLIP(RALM.K,MXLM4,0,SREF)
44C     MXLM3=(3)(MXLM)/4
20C     MXLM4=MXLM/4
49A     VLLM.K=SWITCH(0,VLM.K,DSLM.K)
7A      DSLM.K=MXLM5-DSPLM.K
44C     MXLM5=(MXLM)(5)/12
1L      DSPLM.K=DSPLM.J+(DT)(VLM.JK-DMPLM.JK)
20R     DMPLM.KL=DMPL1.K/DT
49A     DMPL1.K=SWITCH(0,VLML.K,DSPLM.J)
12R     VLML.KL=100000
14R     VLM.KL=AVLM2+(AVLM4)(SLXLM.K)
20C     AVLM2=AVLM/2
20C     AVLM4=AVLM/4
31A     SLXLM.K=(-1)SIN((2PI)(XLM.J)/TPP)
C       AVLM=500

7N      XHM=11500
1L      XHM.K=XHM.J+(DT)(VELHM.JK-0)
44R     VELHM.KL=(SREF)(VEHM.K)/DT
51A     VEHM.K=CLIP(0,VLHM.K,MDHM.K,RDHM.K)
51A     MDHM.K=CLIP(MXHM3,RAHM.K,0,SREF)
51A     RDHM.K=CLIP(RAHM.K,MXHM4,0,SREF)
44C     MXHM3=(3)(MXHM)/4
20C     MXHM4=MXHM/4
49A     VLHM.K=SWITCH(0,VHM.K,DSHM.K)
7A      DSHM.K=MXHM5-DSPHM.K
44C     MXHM5=(MXHM)(5)/12
1L      DSPHM.K=DSPHM.J+(DT)(VHM.JK-DMPHM.JK)
20R     DMPHM.KL=DMPHM1.K/DT
49A     DMPHM1.K=SWITCH(0,VLMHM.K,DSPHM.J)
12R      VLMHM.K=100000
14R     VHM.KL=AVHM2+(AVHM4)(SLXHM.K)
20C     AVHM2=AVHM/2
20C     AVHM4=AVHM/4
31A     SLXHM.K=(-1)SIN((2PI)(XHM.J)/TPP)
C       AVHM=600
```

```
7N      XG=X+12000
1L      XG.K=XG.J+(DT)(VELG.JK-0)
44R     VELG.KL=(SREF)(VEG.K)/DT
51A     VEG.K=CLIP(0,VLG.K,MDG.K,RDG.K)
51A     MDG.K=CLIP(MXG3,RAG.K,0,SREF)
51A     RDG.K=CLIP(RAG.K,MXG4,0,SREF)
44C     MXG3=(3)(MXG)/4
20C     MXG4=MXG/4
49A     VLG.K=SWITCH(0,VG.K,DSG.K)
7A      DSG.K=MXG5-DSPG.K
44C     MXG5=(MXG)(5)/12
1L      DSPG.K=DSPG.J+(DT)(VG.JK-DMPG.JK)
20R     DMPG.KL=DMPG1.K/DT
49A     DMPG1.K=SWITCH(0,VLMG.K,DSPG.J)
12R     VLMG.KL=100000



14A     VG.K=AVG2+(AVG4)(SLXG.K)
20C     AVG2=AVG/2
20C     AVG4=AVG/4
31A     SLXG.K=(-1)SIN((2PI)(XG.J)/TPP)
C       AVG=700
        RANGES

        FRIENDLY RANGES
7A      RA60.K=ETG.K-X60.K
7A      RA81.K=EETG.K-X81.K
7A      RA42.K=EETG.K-X42.K
7A      RAH.K=EETG.K-XH.K

        ENEMY RANGES
7A      RALM.K=XLM.K-FFTG.K
7A      RAHM.K=XHM.K-FFTG.K
7A      RAG.K=XG.K-FFTG.K
51A     EETG.K=CLIP(FCTG.K,ETG.K,RANDD.K,800)
51A     ECTG.K=CLIP(XLM.K,ECT1.K,CALM.K,CALV.K)
51A     CALV.K=CLIP(CAHM.K,CAG.K,CAHM.K,CAG.K)
51A     ECT1.K=CLIP(XHM.K,XG.K,CAHM.K,CAG.K)
51A     FFTG.K=CLIP(FCTG.K,FTG.K,RANDD.J,800)
51A     FCTG.K=CLIP(X60.K,FCT1.K,CA60.K,CA6V.K)
51A     CA6V.K=CLIP(CA81.K,CA4H.K,CA81.K,CA4H.K)
51A     CA4H.K=CLIP(CA42.K,CAH.K,CA42.K,CAH.K)
51A     FCT1.K=CLIP(X81.K,FCT2.K,CA81.K,CA8V.K)
51A     CA8V.K=CLIP(CA42.K,CAH.K,CA42.K,CAH.K)
51A     FCT2.K=CLIP(X42.K,XH.K,CA42.K,CAH.K)
C       MX60=1780
C       MX81=4560
C       MX42=5650
C       MXH=11000
C       MXLM=4500
C       MXHM=6000
C       MXG=13000
6N      DSP60=0
6N      DSP81=0
6N      DSP42=0
6N      DSPH=0
6N      DSPLM=0
6N      DSPHM=0
6N      DSPG=0
C       TPP=2000
C       X=0
```

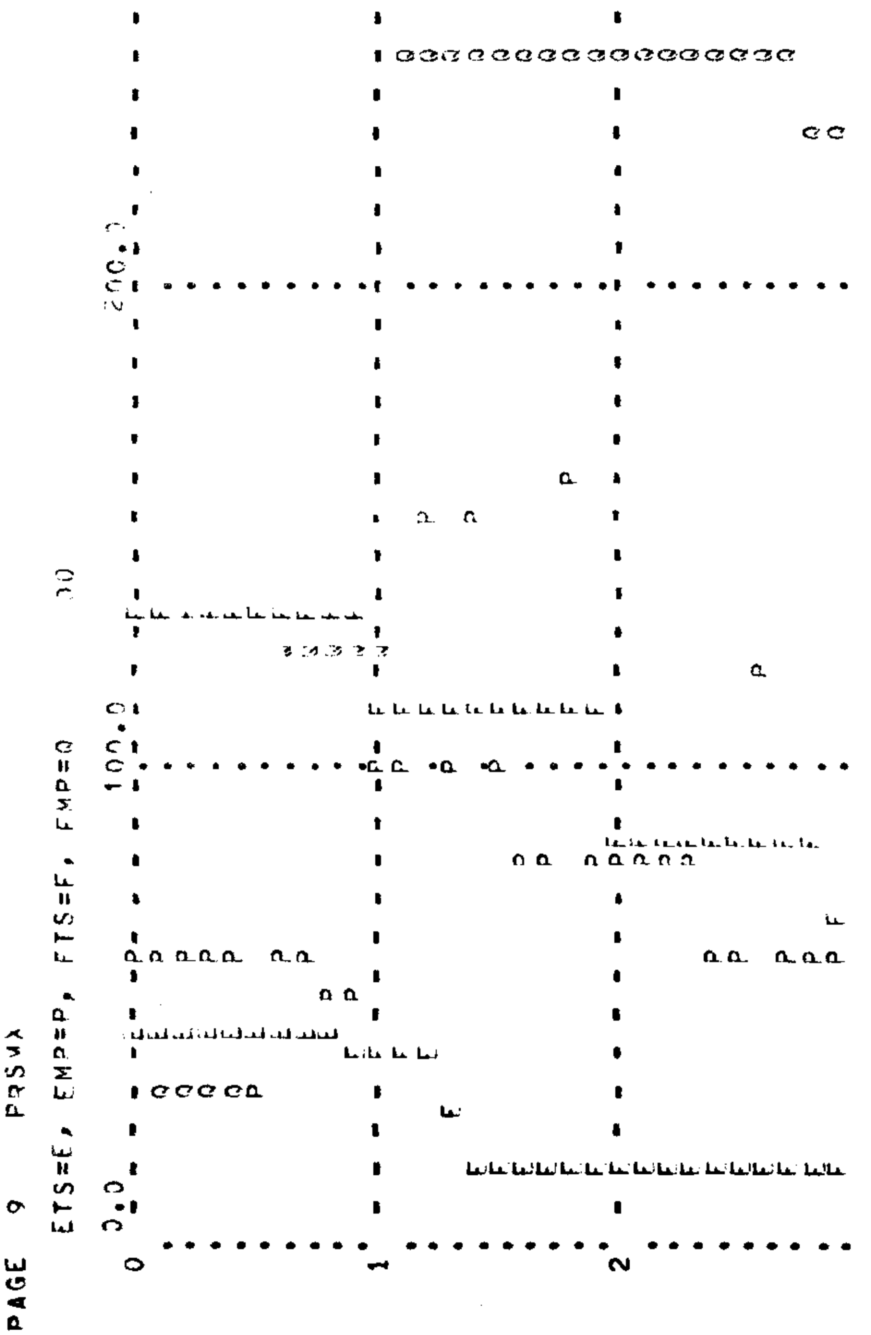
```
        INITIAL CONDITIONS
6N      FT1=132
51N     ET1=CLIP(44,396,SREF,0)
6A      EUA=1
6N      FUA=1
6N      EMD=0
6N      EAELM=0
6N      EALM=FDLLM
6N      EAEHM=0
6N      EAHM=FDLHM
6N      FAEG=0
6N      EAG=EDLG
6N      EMIP=0
6N      FMD=0
6N      FAE60=6
6N      FA60=FDL60
6N      FAE81=0
6N      FA81=FDL81
6N      FAE42=0
6N      FA42=FDL42
6N      FAEH=0
6N      FAH=FDLH
6N      FMIP=0
6N      FMB=2
6N      EMB=2
6N      TSH60=0
6N      TSH81=3
6N      TSH42=4
6N      TSHH=6
51N     TSHLM=CLIP(18,6,0,SREF)
6N      TSHHM=6
6N      TSHG=0
```

```
C       SREF=-1
PRINT   1)ETS/2)FMP/3)FMD/4)FMET/5)PFTK/6)ETD/7)EE/8)EUA/9)ETG/10)XLM
PRINT   11)XHM/12)XG/13)*
PRINT   1)FTS/2)EMP/3)EMD/4)EMET/5)PFTK/6)FTD/7)FE/8)FUA/9)FTG/10)X60
PRINT   11)X81/12)X42/13)XH
PRINT   1)FMIP/2)FMACR/3)FMDR/4)FMB/5)FMAR
PRINT   1)EMIP/2)EMACR/3)EMDR/4)EMB/5)EMAR
PRINT   10)WSH60/11)ASH60/12)MSH60/13)TSH60/14)USH60
PRINT   10)WSH81/11)ASH81/12)MSH81/13)TSH81/14)USH81
PRINT   10)WSH42/11)ASH42/12)MSH42/13)TSH42/14)USH42
PRINT   10)WSHH/11)ASHH/12)MSHH/13)TSHH/14)USHH
PRINT   1)WSHL/2)ASHL/3)MSHLM/4)TSHLM/5)USHLM
PRINT   1)WSHM/2)ASHM/3)MSHHM/4)TSHHM/5)USHHM
PRINT   1)WSG/2)ASHG/3)MSHG/4)TSHG/5)USHG
PRINT   1)CALM/2)CAHM/3)CAG/6)CA60/7)CA81/8)CA42/9)CAH
PRINT   1)ETLR/2)EWLR/3)FTLR/4)FWLR
SPEC     DT=0.1/LENGTH=3/PRTPER=0.1/PLTPER=0.1
```

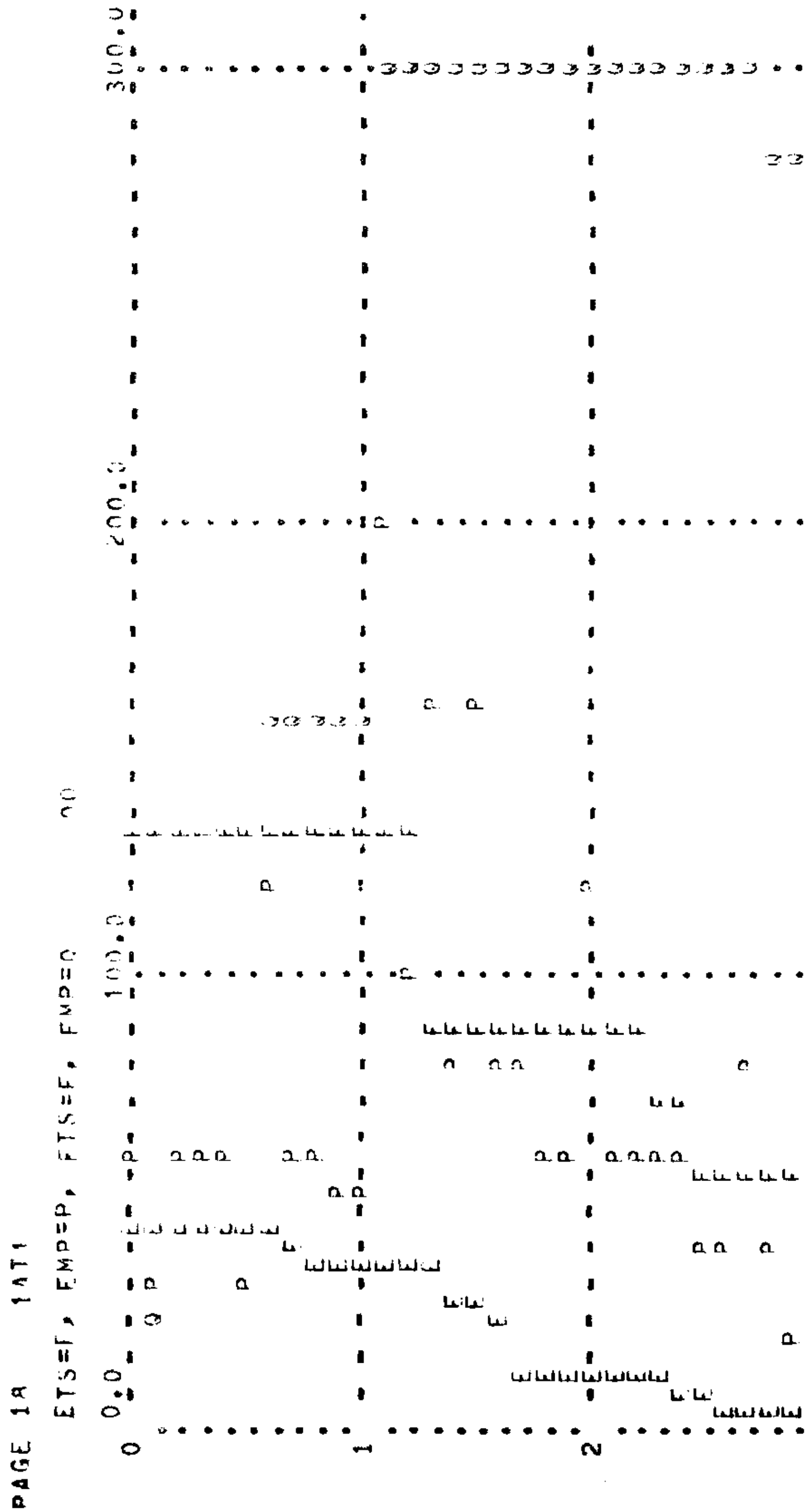
APPENDIX I

BASE MIX VALIDATION RUNS

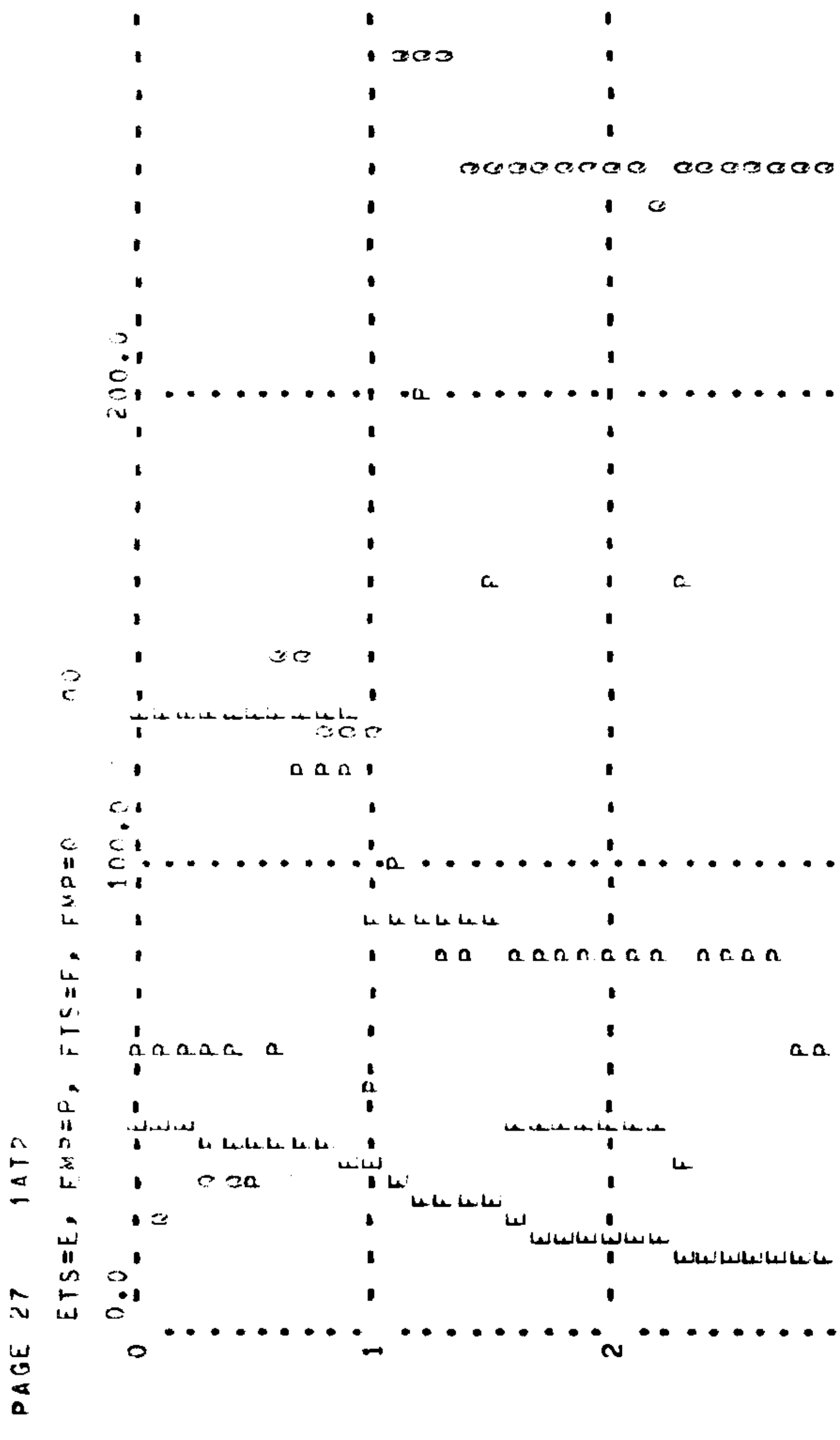
Run No. 1 (Attack)



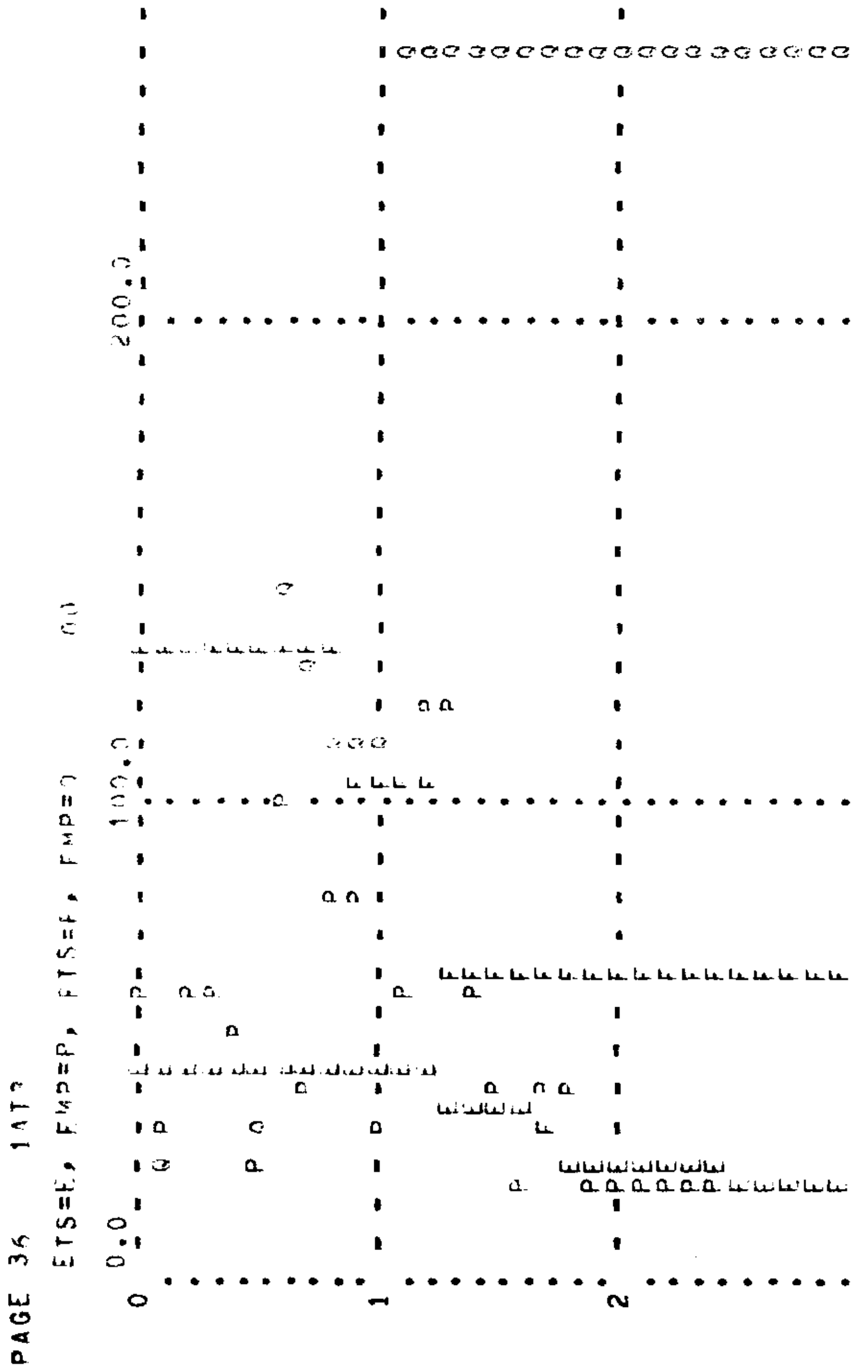
Run No. 2 (Attack)



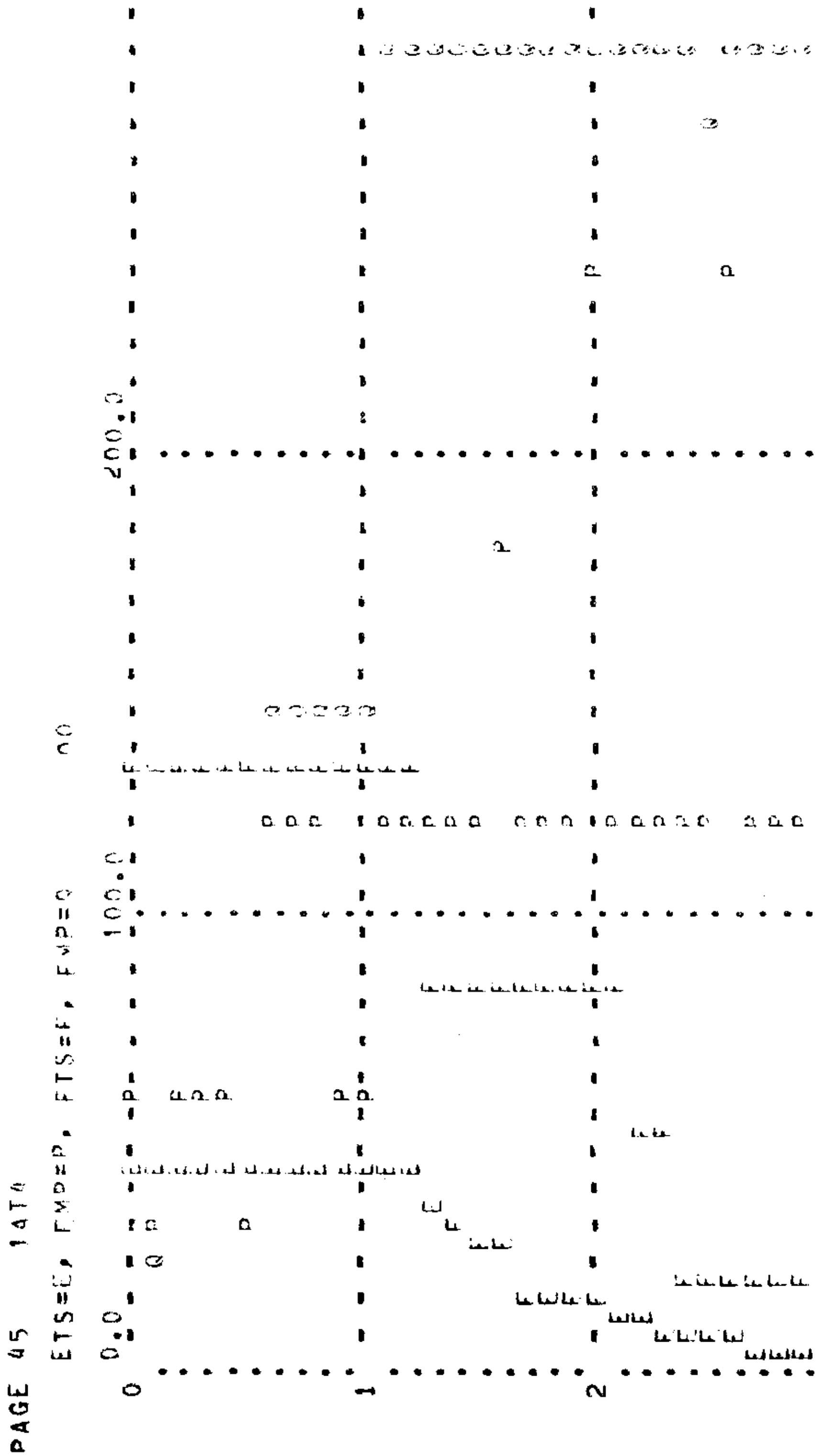
Run No. 3 (Attack)



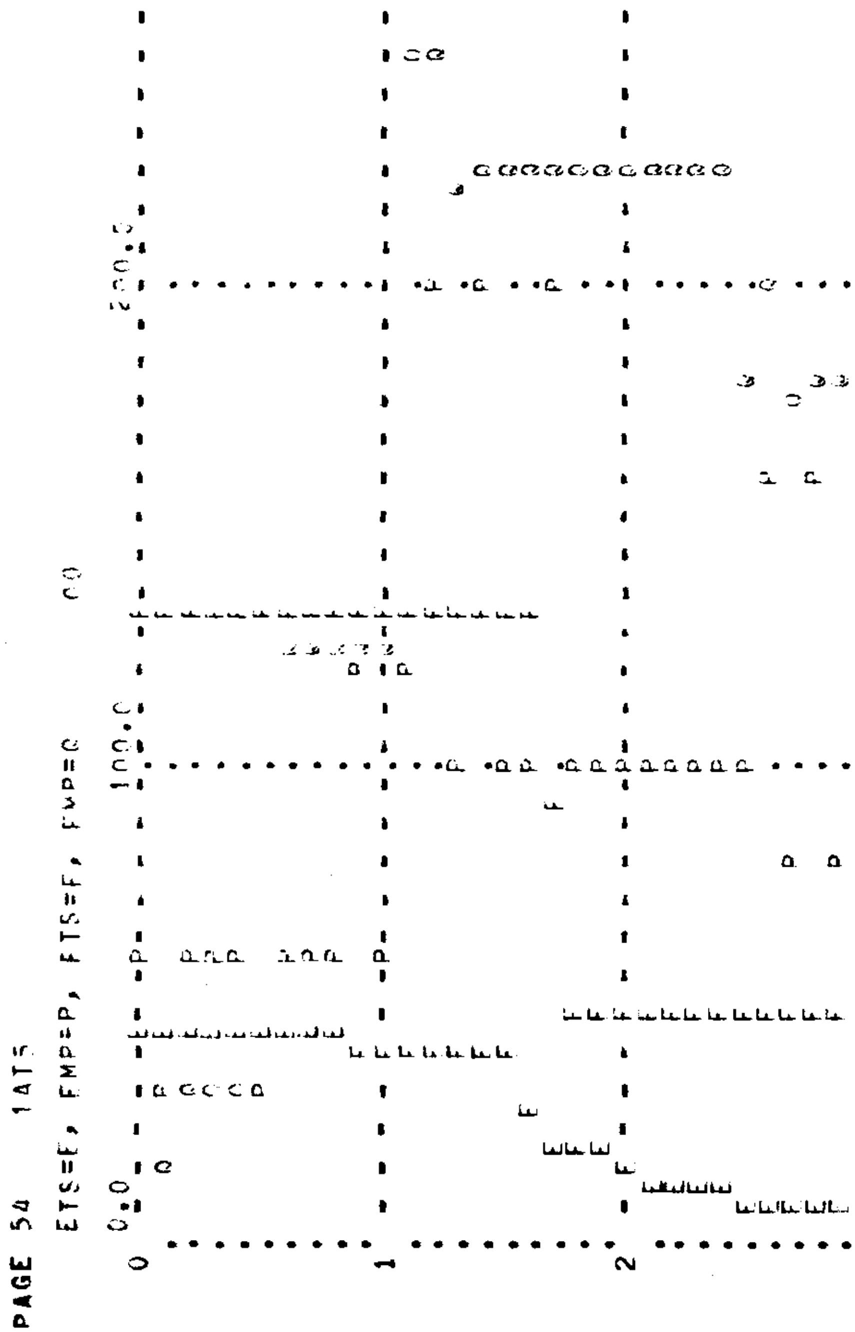
Run No. 4 (Attack)



Run No. 5 (Attack)



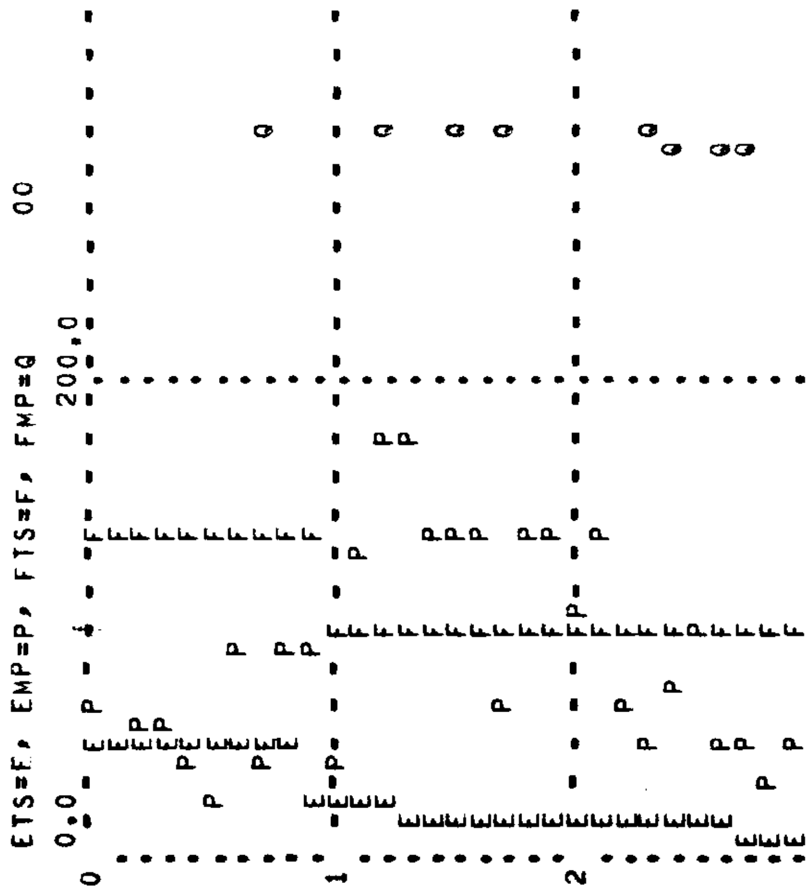
Run No. 6 (Attack)



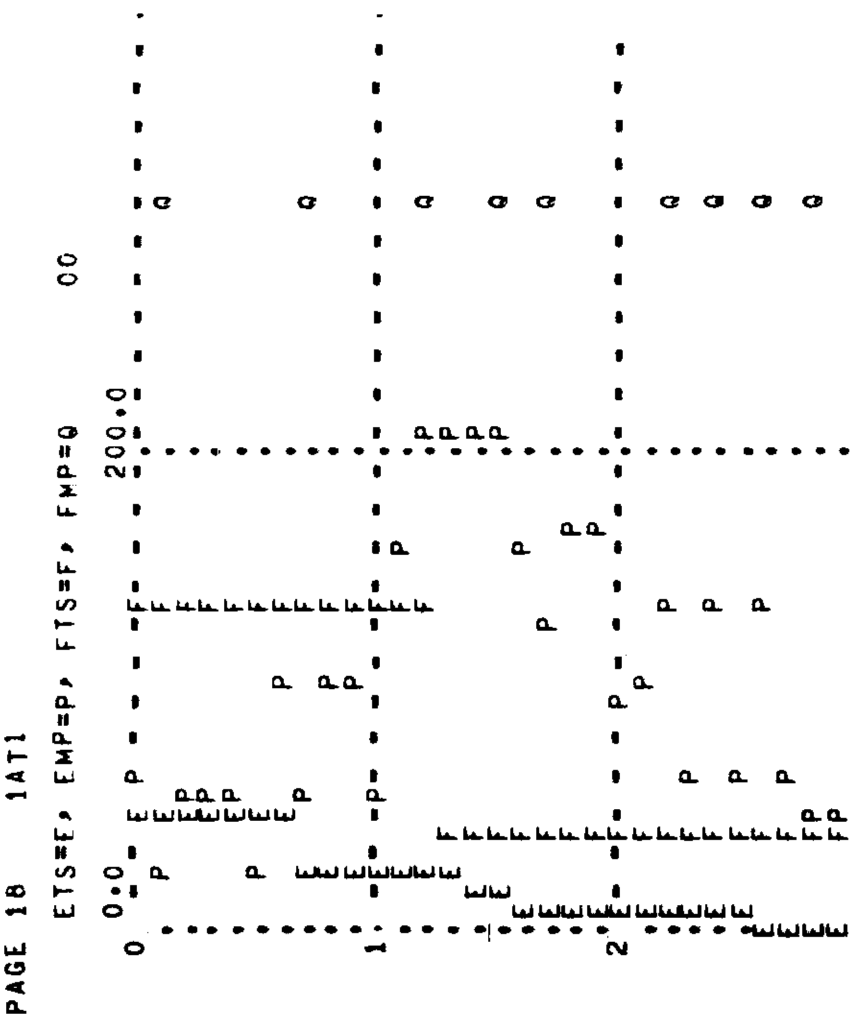
APPENDIX J

ALL 60 mm MIX RUNS

Run No. 1 (Attack)



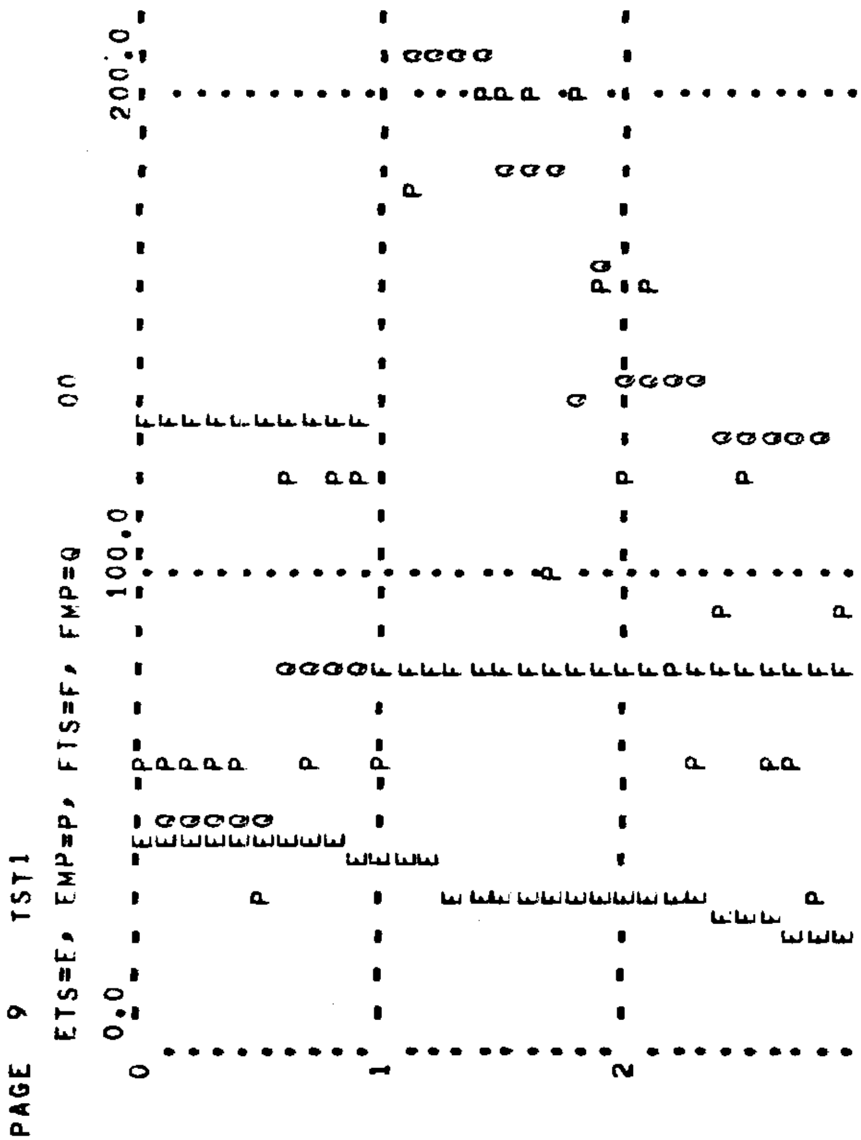
Run No. 2 (Attack)



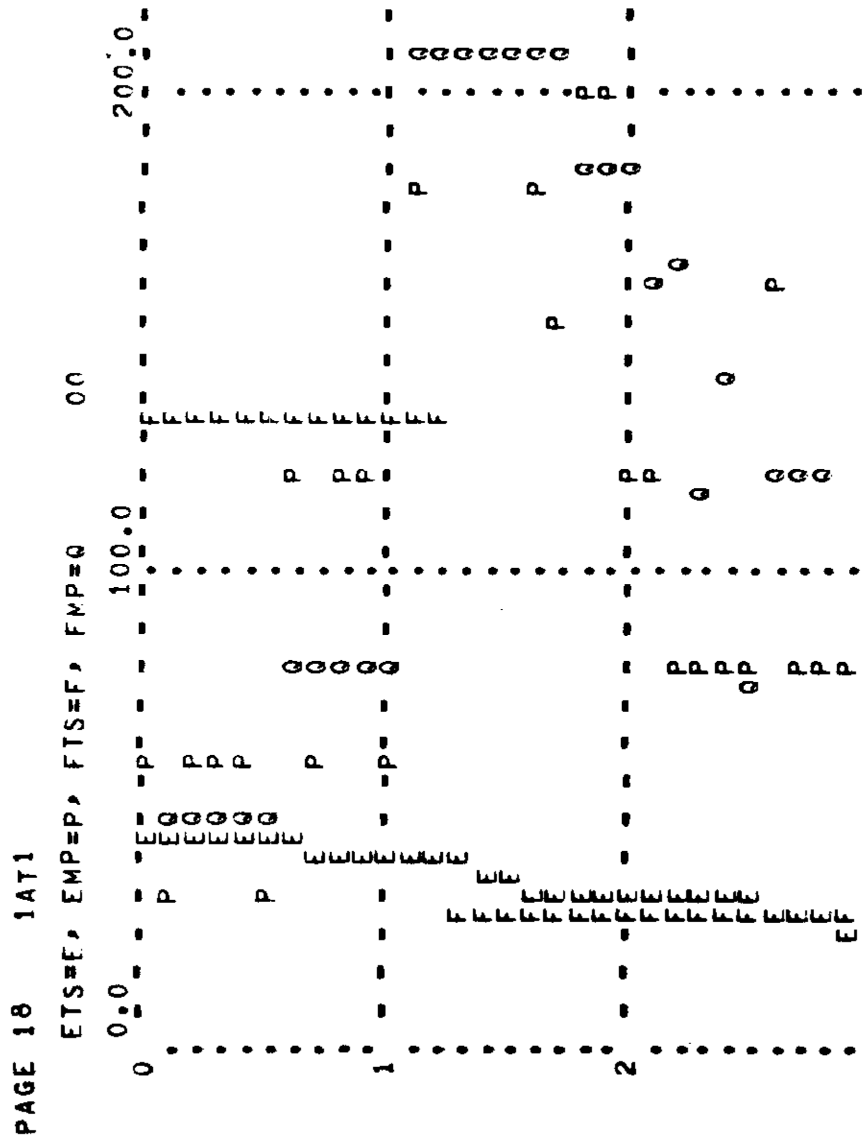
APPENDIX K

INCREASED 81 mm MIX RUNS

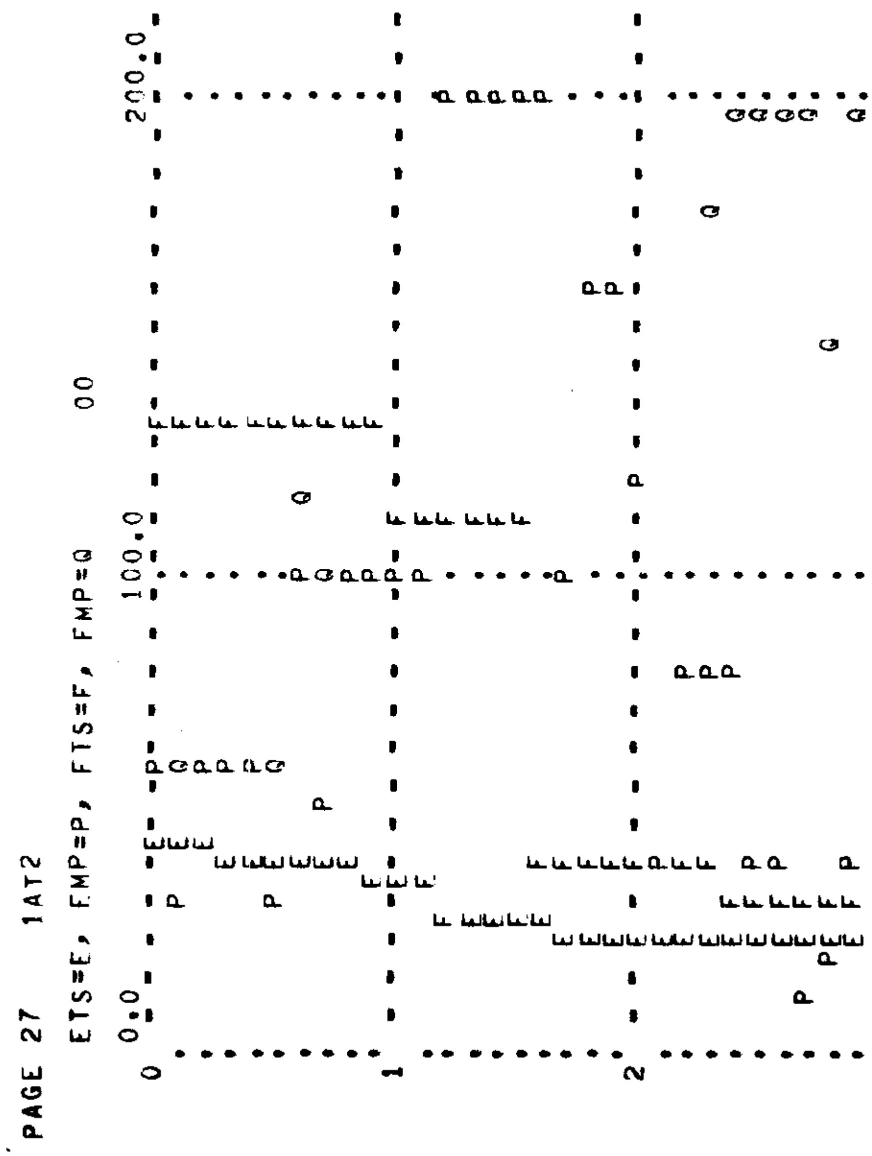
Run No. 1 (Attack)



Run No. 2 (Attack)



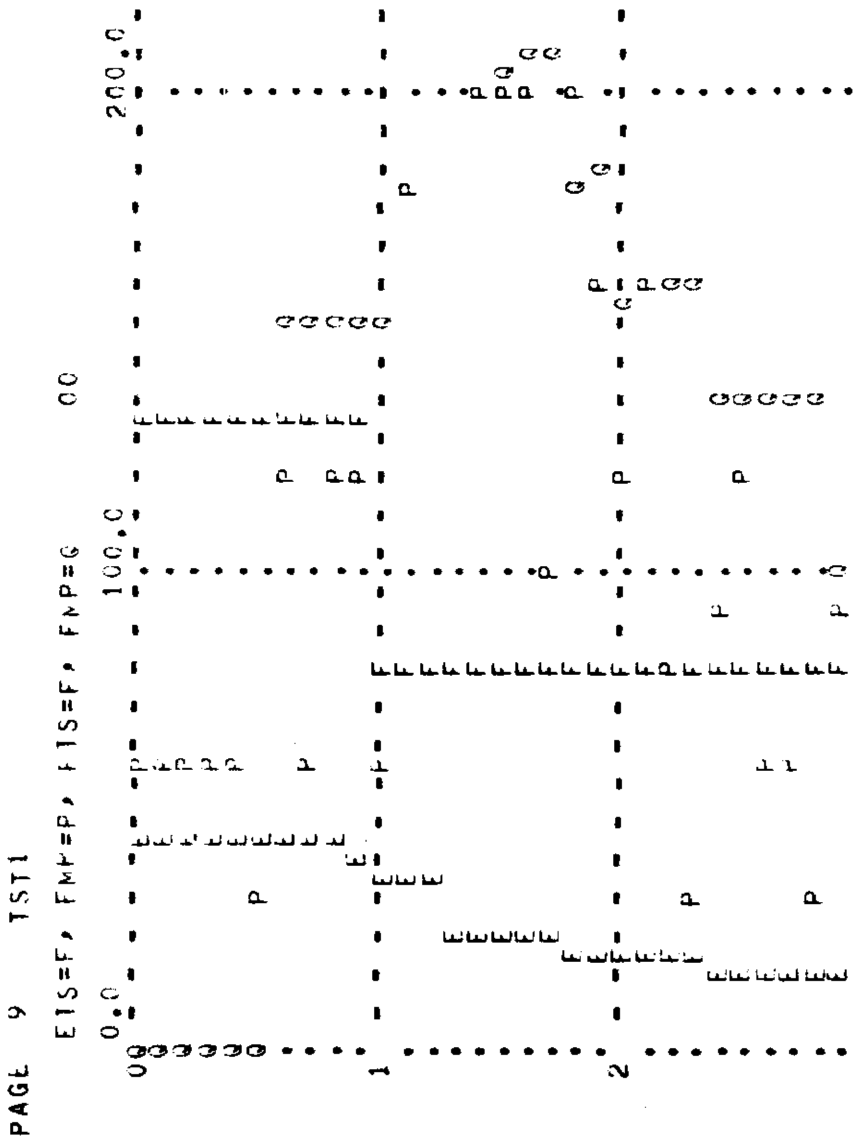
Run No. 3 (Attack)



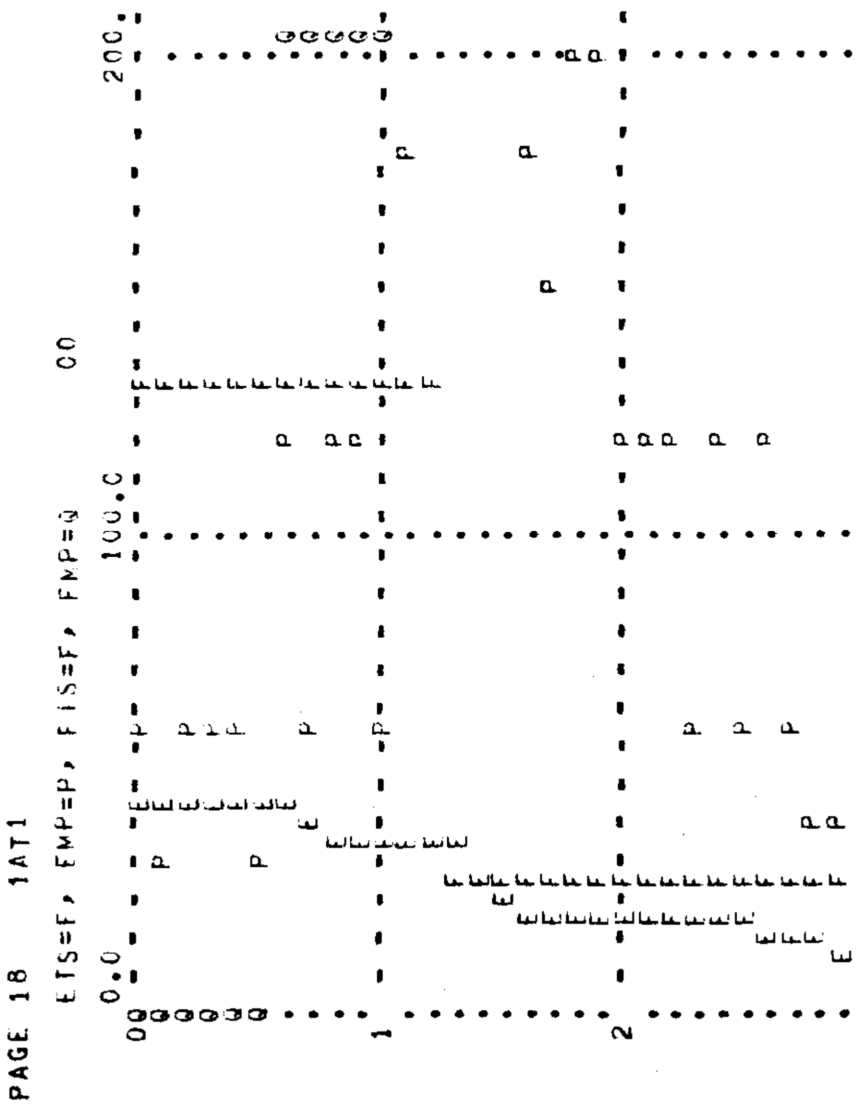
APPENDIX L

INCREASED 4.2 inch MIX RUNS

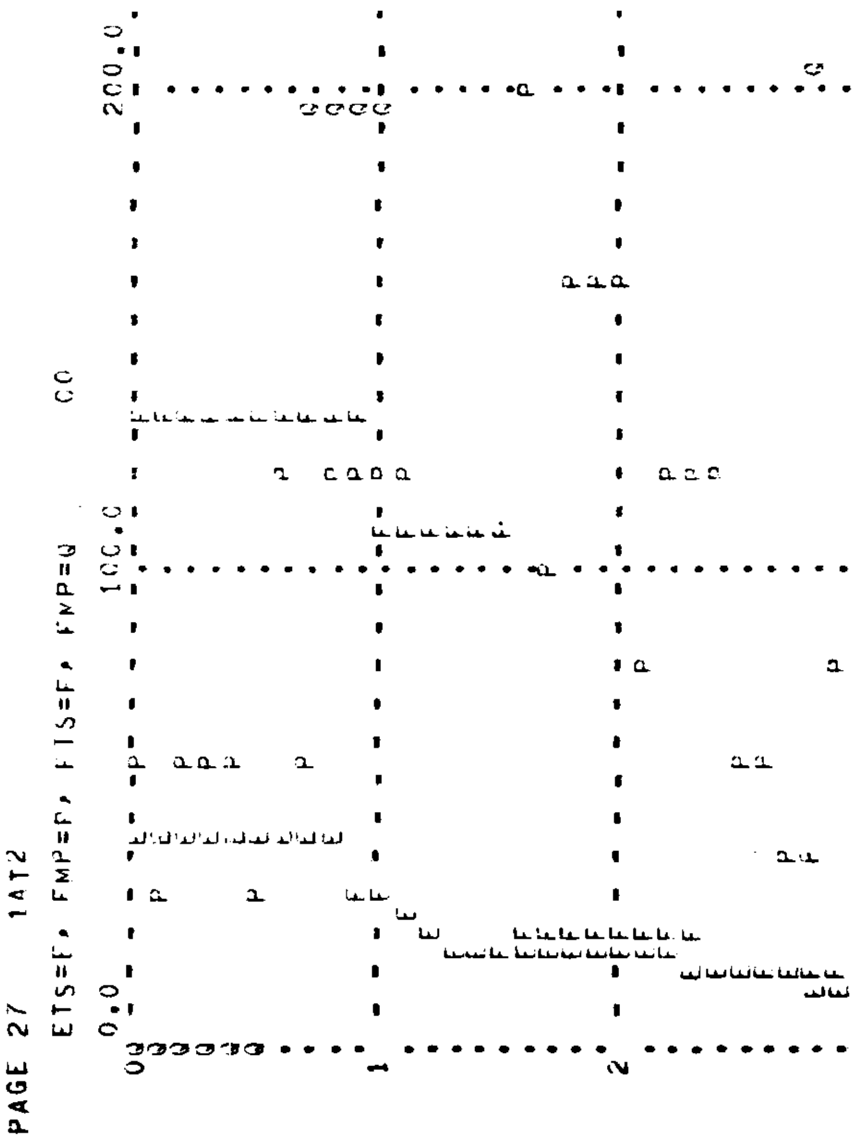
Run No. 1



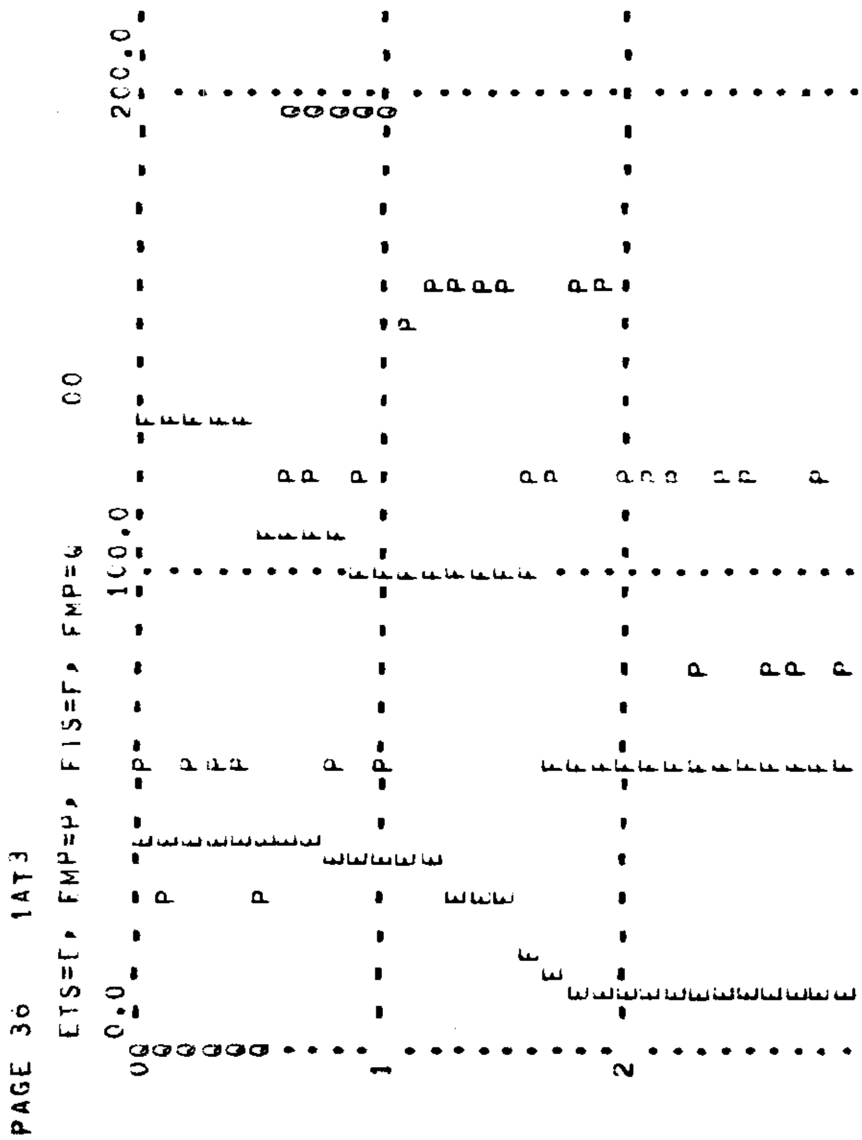
Run No. 2



Run No. 3



Run No. 4



BIBLIOGRAPHY

Literature Cited

1. United States Army Infantry Board, Final Report Infantry Weapons Test Methodology Study, Infantry Indirect-fire Weapons Methodology Review, Fort Benning, Georgia, June, 1971.

2. Lanchester, F. W., Aircraft in Modern Warfare: The Dawn of the Fourth Arm, Constable and Company, London, 1916.

3. Bonder, Seth, An Analytic Model of Ground Combat: Design and Application, The University of Michigan, Vector Research, Inc., 1971.

4. Zimmerman, Richard E., "Simulation of Tactical War Games," Operations Research and Systems Engineering, Edited by Charles D. Flagle, William H. Huggins, Robert H. Ray, The Johns Hopkins Press, Baltimore, 1954.

5. Army Strategic Tactics Analysis Group, "Development of CENTAUR," A Computerized War Game, AD-296460, December, 1962.

6. Army Strategic Tactics Analysis Group, Draft Study of Legion for the Secretary of Defense, (unpublished).

7. United States Army Combat Development Command, Tank, Antitank and Assault Weapons Requirements Study (U), Phase III, Individual Unit Action Simulation Model, Fort Knox, Kentucky, December, 1968.

8. Clark, Gordon M. and Samuel H. Parrey, Small Unit Combat Simulation (DYNTACS X), Counterbattery Fire Models Final Report, Systems Research Group, Department of Industrial Engineering, The Ohio State University, October, 1970.

9. Bonder, Seth, "The Lanchester Attrition-Rate Coefficient," Operations Research, March-April 1967, pp. 221-232.

10. Bonder, Seth and Robert Farrell, Final Report, Development of Analytical Models of Battalion Task Force Activities, Systems Research Laboratory Department of Industrial Engineering, The University of Michigan, September, 1970.

11. Pugh, Alexander L., III, Dynamo User's Manual, Second Edition, the M.I.T. Press, Massachusetts Institute of Technology, 1963.

12. Forrester, Jay W., Industrial Dynamics, The M.I.T. Press, Massachusetts Institute of Technology, 1962.

13. Meyer, Donald Leonard, "A Dynamo Simulation of a Complex Military Tactical Model," M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1968.

14. Davis, Reed D., "A Dynamo Simulation of an Assault River Crossing," M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1967.

15. Faulkender, Robert W., "Use of Industrial Dynamics in Simulation of an Insurgent Activity," M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1967.

16. Abele, Louis E., "Use of Industrial Dynamics in the Simulation of Military Combat Models," M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1966.

17. Krol, Joseph, "Computer Simulated Models of Lanchester-type Combat," to be published by Wiley.

18. Forrester, Jay, Industrial Dynamics, The M.I.T. Press, Massachusetts Institute of Technology, 1962, p. 13.

19. Department of the Army, "Mathematics of Military Action, Operations and Systems," Pamphlet Number 70-5, Washington, D.C., January, 1968.

20. Bonder, Seth and John Honig, "An Analytical Model of Ground Combat: Design and Application," Unpublished paper.

21. Quade, Edward S. and W. I. Boucher, Systems Analysis and Policy Planning, Applications in Defense, American Elsevier Publishing Company, New York, 1968.

22. United States Army Infantry School, Infantry Reference Data, Fort Benning, Georgia, 1968.

23. Department of the Army, "Handbook on Aggressor Military Fires, FM-30-102, Washington, D.C., Marcy, 1966.

24. Department of the Army, Supply Bulletin 700-20, Washington, D.C., November, 1971.

Other References

Bertils, Bertel Randolph, "A GPSS II Simulation Model to Evaluate Terrain Capabilities of Typical Pulpwood Harvesting Vehicles," M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1970.

Department of the Army, "The Rifle Company, Platoons and Squads," FM 7-10, Washington, D.C., April,1970.

Department of the Army, "Staff Officers Field Manual, Staff Organization and Procedure," FM 101-5, Washington, D.C., June, 1968.

Department of the Army, "Staff Officer's Field Manual, Organization, Technical, and Logistical Data, Unclassified Data," FM 101-10-1, Washington, D.C., January, 1966.

Knight, John E. and William W. Hines, "Complex Systems Analysis of Water Quality Dynamics," the Feedback Systems Structure, School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, Georgia, 1970.

Mellonics Division, Litton Systems Inc., "Project Analysis, Indirect Fire Facility," Contract DAEA18-68-C-1004, Monterey, California, 1969.

Mellonics Division, Litton Systems Inc., "Summary of CDCEC Range Support Plans for Measurement of Indirect Fire Effectiveness of Weapons Organic to Infantry Units," Monterey, California, 1968.

Naylor, Thomas H. and J. M. Finger, "Verification of Computer Simulation Models," Management Science, October, 1967.

Solnyshkov, Yu. S., "Optimization of Armament Selection," Optimizatsiya Vybora Vooruzheniya, 1968, Translated by Translation Division, Foreign Technology Division, United States Air Force, Wright Patterson Air Force Base, September, 1969.

United States Army Combat Developments Command Armor Agency, "TATAWS III - A Case History and Analysis," Fort Knox, Kentucky, October, 1969.

United States Army Infantry School, Artillery Handbook, Fort Benning, Georgia, March, 1967.

United States Army Infantry School, Tactical Operations Handbook, Fort Benning, Georgia, July, 1968.